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The Moon Illusion

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THE fact that the horizon moon is much larger in perceived size than the moon in the heavens is so obvious that it must have been recognized by primitive man, even though there are still many persons, some of them with Ph.D.'s as well as many city dwellers without Ph.D.'s, who have never heard of this phenomenon.[1] The great Ptolemy described the phenomenon, noting correctly that it holds not only for the moon, but also for the sun as seen through fog and for the constellations. The phenomenon would thus seem to be celestial. Ptolemy suggested that the great perceived size of the horizon moon may be due to its comparison with terrestrial objects, and this is the most common explanation today.

Stated so simply the explanation makes no sense, however. Why should contrast make the moon seem large rather than small? The horizon moon subtends the same angle as an horizon object 230 ft wide 5 mi away, or as an object 46 ft wide 1 mi away. So the moon is, in this sense, "bigger" than a house, although smaller than a field or a hill. If it looks large by contrast, it must be because a smaller size is expected. Undoubtedly there is a contrast effect, one that makes the horizon moon seem large as compared with the memory of the more familiar moon in elevation, but this contrast is a consequence of the illusion, not its cause.

This common explanation does, however, insufficient justice to Ptolemy. He was not so naive. When he spoke of the comparison of the horizon moon with terrestrial objects he was thinking, not of the objects at the horizon, but of the objects between the horizon and the observer. An extent of filled space is nearly always perceived as greater than the same extent of empty space. The horizon, Ptolemy thought, ought to look farther away than the zenith, and that might make the horizon moon look larger than the zenith moon.[2]

Ptolemy's theory, elaborated by many philosophers, is illustrated in Fig. 1, in a diagram similar to one drawn by Robert Smith in 1738.[3] If the zenith is perceived as nearer the observer than is the horizon, then the arch of the heavens would appear to be ellipsoidal, as if extending along the curve *HzH* for an observer at *O*. Actually the moon more nearly describes an arc of a circle *HZH* and always (practically) subtends the same angle at *O*, as shown in Fig. 1. Thus the moon, actually at the zenith *Z*, appears to be at a nearer, false zenith *z*, and looks smaller than it would if perceived farther away. If a near object subtends the same angle as a

[1] For the history of thought and research on the moon illusion, see E. Reimann, "Die scheinbare Vergrösserung der Sonne und des Mondes am Horizont," Zeits. f. Psychol. **30**, 1–38, 161–195 (1902).

[2] Cf. H. Helmholtz, *Physiological optics* (1866, tr. 1910), vol. III, pp. 290–292, 360–362.

[3] R. Smith, *A compleat system of opticks* (1738), vol. I, pp. 49–70, esp. pp. 62–67.

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far object, the near object must be smaller than the far—that is the argument. The argument was plausible enough, because comparison with terrestrial objects between the observer and the horizon ought to make the distance to the horizon seem greater than the empty undifferentiated distance to the zenith.

Yet the argument is wrong for the simple reason that the moon in elevation looks farther away than the moon on the horizon—to all who have observed the moon much and thought about the matter. If asked why, they say, "The moon is so much smaller in elevation; of course, because it looks farther away"—thus inverting Ptolemy's logic.

If the moon appeared to be nearer at the zenith than at the horizon, then certainly it ought to seem smaller at the zenith. Perceived size is known to be thus dependent upon perceived distance. The brain habitually corrects the size of the retinal image for the distance of the object. A man 40 ft away puts on the retina an image half as tall as a man 20 ft away, but he looks just about the same size, because his distance away is perceived and a correction is made in the perception.[4] But in the case of the moon it is not the perceived distance that determines the perceived size. On the contrary, the perceived size would seem to determine the perceived distance.

There has been no end of discussion of the moon illusion. Both Gauss and Helmholtz proposed studying the phenomenon with mirrors, but never undertook the experiment. They would have had trouble. The horizon moon is apt not to look large when seen in a small imperfect mirror.

The amount of the change in perceived size of the moon was measured by Pozděna in 1909.[5] He equated the size of an artificial moon close at hand to the size of the real moon at different elevations, and he found the ratio of the perceived diameter of the elevated moon to the perceived diameter of the horizon moon to be about 1/2.5.

[4] E. G. Boring, "Size constancy and Emmert's law," Am. J. Psychol. **53**, 293–295 (1940); A. H. Holway and E. G. Boring, "Determinants of apparent visual size with distance variant," Am. J. Psychol. **54**, 21–37 (1941).

[5] R. F. Pozděna, "Eine Methode zur experimentellen und konstruktiven Bestimmung der Form des Firmamentes," Zeits. f. Psychol. **51**, 200–246 (1909).

Schur in 1925 showed that this phenomenon is not necessarily celestial.[6] It appears for terrestrial artificial moons if the distances are but great enough. She found a ratio of the diameter of the zenith moon to the diameter of the horizon moon of 1/1.2, when the moons were 4 m away, and of $\frac{1}{2}$ when the moons were 33 m away. Since the change in this ratio was asymptotic to the ratio $\frac{1}{2}$, she concluded that the illusion would hold in maximum amount for distances beyond 33 m. She worked indoors and did not find it practicable to get an artificial zenith more than 33 m above the floor. Her finding means that the illusion holds for the moon in elevation at those greater distances where the clues to the perception of the distance are not fully adequate. Since one can easily perceive 33 m along the ground, this result also suggests that the illusion is really the smallness of the moon in elevation when seen through empty space, not its bigness on the horizon. That is about how the problem stood until recently.

IS THE PHENOMENON PHYSICAL?

The evidence is overwhelming that this phenomenon depends upon the physiological properties of the observer and not upon physical factors external to him—not upon refraction, nor upon atmospheric haze which might make the horizon look more distant than the zenith. Here are some of the reasons.

The difference in size does not appear in photographs. The camera is fairly faithful to the subtended angle. I have seen one photograph, made by the late W. R. Warner who constructed the Lick telescope. It shows the moon successively at different elevations on the same negative. The diameter of the image *increases* about 20 percent as the moon rises, due undoubtedly in part to creeping on the plate, for the moon in elevation shines through less atmosphere and is brighter. This enlargement is too great for the 2 percent increase that would be caused by the fact that the zenith moon is nearer to the observer by the radius of the earth.

If the large horizon moon is viewed through any physical instrument that is perceived by the observer as near to him, then the perceived moon

[6] E. Schur, "Mondtäuschung und Sehgrosskonstanz," Psychol. Forsch. **7**, 44–80 (1925).

loses its great size. That is why it usually looks small in a poor mirror where the glass or the frame is visible. The horizon moon looks small when viewed through a tube or when pinched between the thumb and forefinger. Bring your fingers tangent to the limbs of the horizon moon and it shrinks at once. Take your fingers away, and it snaps back to its inflated size.

When the moon is big on the horizon, lie down on your back with your head toward the moon, hanging the head over a log or stone or the edge of a table. The moon, huge but a moment before, is now quite small, small enough to make you exclaim. Or stoop over and view the horizon moon between your legs. Again it shrinks. So the perceived size of the moon must depend on the properties of the biological viewing mechanism and is thus truly an illusion.

CONDITIONS OF THE ILLUSION

Recently a series of experiments on the illusion has been in progress, experiments carried out from 1936 to 1941 by Dr. Holway, Mr. Taylor and myself.[7] We arranged to project an artificial moon on a white cloth screen, 3.5 m away from the observer and placed always a little to one side of the real moon's azimuth. The observer controlled a series of apertures in the projection lantern, adjusting them until the artificial moon matched in perceived size the real moon at its different elevations.

This judgment of equality is not so easy to make as one might think. Abstracted equivalences are always troublesome. Heterochromatic photometry, for instance, is difficult because the observer has to abstract from the hues to equate the brightnesses. These equations of judgments between the real and artificial moons were "heterotelic," that is to say, the observer had to match in size two objects which were at different distances. He cannot, of course, see the size of his own retinal image, and, when he is aware of the distance, then his brain automatically tends to correct for distance—at least approximately when the distances are not too great and there are sufficient clues to tell him what the distance is.[8] The retinal image remains, nevertheless, the primary determinant, so that there is some conflict and uncertainty. A man 40 ft away looks about as large as he did 20 ft away, when he is seen with two eyes in good light with perspective obvious. But a man 1000 ft away looks smaller than one 20 ft away even under the same good conditions for knowing about distance—just as parallel railroad tracks seem to get closer together in the distance. This difficulty of the judgment accounts for some of its variability.

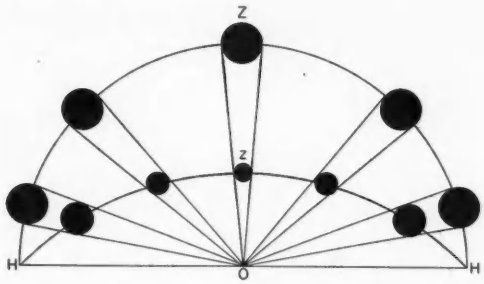

FIG. 1. Ptolemy's theory of the moon illusion: O=observer; H,H=horizon; Z=true zenith; z=perceived zenith. [Adapted from Robert Smith (1738).]

We also used mirrors in the apparatus shown in Fig. 2. There is no reason why mirrors should not be used, provided they are invisible. These mirrors were front-aluminized optical surfaces without frames. They were placed at the ends of long 5-m arms, which could be rotated to place a moon at any desired elevation. We had two arms and two mirrors so that two moons at different elevations could be compared directly.

The black arms and the black clips that hold the mirrors are quite invisible when a bright moon is shining at one from the mirrors, but there is a difficulty. The mirror cannot be placed near the real moon, but opposite against a dark part of the sky. Then on a hazy night the mirror is no longer invisible, because it becomes a rectangular patch of bright haze seen against the black sky behind it. So the illusion then fails to appear, as is almost always the case with visible mirrors. It is often better, therefore, to use the real moon, if only one has the patience to wait month after month for cloudless nights

[7] A. H. Holway and E. G. Boring, "The moon illusion and the angle of regard," Am. J. Psychol. **53**, 109–116 (1940); "The apparent size of the moon as a function of the angle of regard: further experiments," Am. J. Psychol. **53**, 537–553 (1940); D. W. Taylor and E. G. Boring, "The moon illusion as a function of binocular regard," Am. J. Psychol. **55**, 189–201 (1942).

[8] Holway and Boring, reference 4 (1941).

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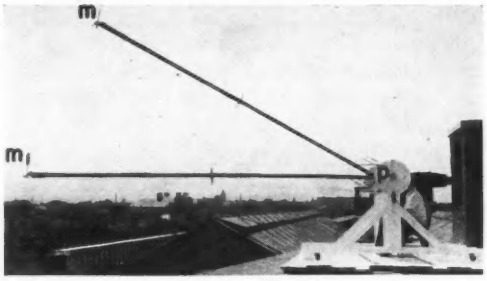

FIG. 2. Mirrors for the moon illusion. The positions of the mirrors m, m are controlled by strings. Each mirror is at the end of an arm that can be elevated, and the angle of elevation is read on the protractor p. The observer has his head (behind the protractor) immobilized by his biting firmly on a rigid biting-board. The projection screen for an artificial moon is not shown.

when the moon is full and to stay up late enough for nature to provide the desired elevations. Still, without the mirrors we should never have known the size the moon would appear to have if it could be seen below the horizon.

In the early experiments we were able to measure the changing perceived size of the moon as it ascended, but we did not get smooth functions. The observed points fell to one side or the other of what seemed to be the average curve. Then we found the difficulty. We had left the observer free to move his head—just as everyone before us had done. When you look at the moon in nature you move your head, or your eyes, or more often both.

If the head is fixed in a vertical position, the eyes can be raised about 40° above the horizontal or a little more. The neck can easily be bent backward another 40°. If you stand erect and look at the zenith, you almost inevitably have to bend the body backward to get the remaining 10°. It is important, therefore, to know whether the eyes are responsible for the illusion or whether it is the neck.

We arranged to immobilize the head by having the observer bite firmly on a horizontal strip of metal, a biting-board, fixed in the apparatus of Fig. 2. We could then study the illusion up to 35°. Vision begins to get blurred when the eyes are raised as much as 40°. We could also make the plane of the biting-board vertical, so as to work with a supine observer who was looking straight ahead at the zenith. Finally, we pivoted the biting-board in such a way that the head could move and leave the eyes always looking straight in front at a mirrored moon.

Here is what happens. For the erect observer the perceived moon gets smaller as it ascends from 0° (straight ahead) to 35°, and the full amount of shrinkage is reached in that span. Figure 3 is the average of results for two observers who always agreed pretty well with each other during the six years of experimentation. The ratio of perceived diameters in these data is 1/1.9—about what Schur got with an artificial moon at 33 m, a little less than what Pozděna got for the real moon.

If the observer is supine looking straight ahead at the zenith, the same kind of function is found—only then does one have to use mirrored moons, because the real moon in Massachusetts does not often get to the zenith. If the supine observer hangs his head over the edge of a table to see the moon ascend, then the moon starts small at the horizon and gets larger as it ascends. If the angle of the biting-board is controlled so that the observer always looks straight ahead from his skull at the moon, then there is no illusion. If the moon is placed by mirrors below the horizon, then, for an erect observer, it shrinks as it descends below the horizontal. So the maximum size is straight ahead.

If the supine observer sees the moon rise from 25° below "straight ahead" to 35° above—a total range of 60°, which is all he can get out of his eyes—then the perceived moon first expands up to the straight-ahead position and thereafter contracts.

Strange things happen if the observer is allowed to use only one eye.[9] Immediate memory then affects the perception. If he makes binocular and monocular observations alternately on the same evening, then the illusion holds for monocular observation, although the data are a little less reliable. The binocular judgments have affected the monocular. But, if the observer is made monocular with a patch over one eye for an entire evening, then the illusion fails.

Persons who have lost an eye appear not to have the illusion. Some of them give smooth functions with no change in the perceived size. Others, who are sophisticated about the fact of the illusion, believe that they see it, but do not

[9] Taylor and Boring, reference 7 (1942).

report consistently. Presumably the illusion depends on binocular vision.

There remain two special points for consideration. Why do the perceived angular diameters of Fig. 3 vary between 1.7° and 3.5°, when it is well known that the real moon subtends an angle of only about half a degree? There is no satisfactory answer to this question, but the difference is consistent with what is called the *size-constancy phenomenon*—the fact that a distant object does not look nearly so much smaller than a near object as its retinal image is smaller. These perceived sizes of the real moon are measured by the diameter of an artificial moon only 3.5 m away. If the small image of a distant object matches in perceived size the larger image of a near object, then the image of the near artificial moon must be made larger than the image of the distant real moon if the two are to match. But the precise answer to the question will not be forthcoming until the quantitative relationships that express perceived size as a function of distance have been worked out. Just now we know these functions only up to 200 ft.

The other point concerns the emotional accompaniments of the illusion. When the erect observer sees the large horizon moon he exclaims "Oh!" with a rising inflection—generally. He is surprised and pleased. When a supine observer with head hanging over the table edge, or anyone doubled over and looking between his legs, sees the tiny horizon moon, he exclaims "Oh!" with a falling inflection—generally. He is surprised and disappointed. Why?

The supine observer sees the zenith moon large, but he never exclaims about it. He says it does not appear large to him, yet he equates it to an artificial moon just as large as the artificial moon to which, when erect, he had already equated the horizon moon. Nor does the erect observer ever exclaim about the small size of the moon in elevation. He just takes it for granted, as if that were the size the moon really is.

The answer must lie in memory and expectation. The moon is usually seen in elevation—in cities almost always. That is the size it is. One carries these absolute impressions around with him. Thus the large horizon moon comes as a great surprise. The observer, supine or doubled over, has just been seeing the horizon moon large. He is surprised when his change of position makes it small.

So comparison does come in, but it is not as Ptolemy thought, a comparison with terrestrial objects. It is comparison of the moon with itself seen previously. This fact makes it unsafe to try to demonstrate the nature of the illusion by asking anyone to lie down and observe a zenith moon or one high in elevation. Apparatus for the measurement of the perceived size is needed. But it is always safe to ask him to try shrinking a large horizon moon by doubling over to view it from between his legs.

THEORY

There is no satisfactory further theory for explaining this phenomenon. It is not due to physical causes outside the visual mechanism. It is not due to the greater brightness of the moon in elevation, when atmospheric haze is diminished. It depends on raising or lowering the eyes. Movements of the head, neck and body do not cause it.

The theory most generally held by psychologists cannot be true. It is that the eyes when raised tend, because of the balance of their muscles, to diverge or at least to converge less.

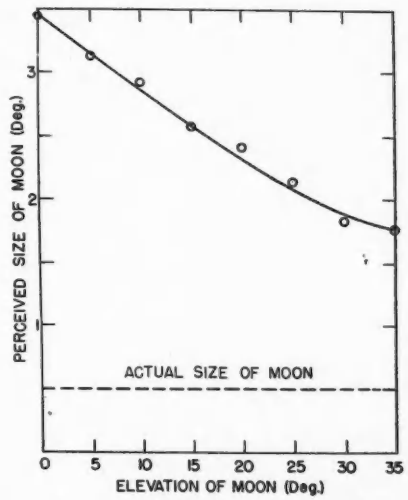

FIG. 3. Perceived size of the moon as a function of its elevation. The curve is the average of data for two observers, erect with heads immobilized. The perceived size is measured by the angle subtended by an artificial moon, equated in size to the real moon but only 3.5 m away.

Thus an effort for convergence is necessary to keep the binocular image from doubling up, and the clue from innervated convergence is the clue to perceived nearer distance. If the theory of Fig. 1 were correct, this clue might explain the illusion; but we have seen that the moon in elevation does not look nearer. It appears to be farther away, because it is seen as smaller. This theory, moreover, would require that the moon below the horizon look still larger than at the horizon, whereas it looks smaller.

When the eyes are raised they also rotate slightly, the one relative to the other, and in such a way as to produce a stereoscopic effect in which high objects would look nearer than low. This theory would work out satisfactorily for the smaller moon below the horizon, but it too is inconsistent with the fact that it is the horizon moon that looks nearest.

There remains only the suggestion that the effort of raising or lowering the eyes shrinks the perceived size of the moon—a theory of inhibition or drainage. Since we do not know why muscular effort in the visual mechanism should affect visually perceived size, in these cases where the clues to perceived distance are missing, we are forced to leave the problem there without ultimate solution.

Atomic Theory from 1904 to 1913

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Foreword

THIS is the first of three articles on the development of the atomic theory of Bohr up to 1915, when Sommerfeld and Wilson made their contributions. In these papers an attempt is made to trace the advancement of some branches of physical theory that accompanied the amazing experimental discoveries of the first 15 years of the century. The outstanding contributions in this field were the revolutionary quantum theory of Planck and the equally revolutionary application of this theory by Bohr to the theory of atomic structure. It is significant how few changes in the theory have been found necessary during the 30 years since the publication of Bohr's first papers. His two-dimensional atom has become three-dimensional; the electron has lost its definite character as a small sphere rotating in a well-defined orbit, but whatever it is, it is still considered to be moving about a central nucleus with a positive charge, and to be the cause of the radiation responsible for line spectra. It has been found necessary to ascribe spin to the electron to account for fine structure. The alpha-particles and electrons which in 1913 were thought to constitute the nucleus have been replaced by protons and neutrons. But the essential features of the early Bohr atom are still recognizable in the 1943 concept of the atom. The purpose of the present papers is to show how these essential features came to be incorporated in his model.

The author takes pleasure in expressing his gratitude for valuable help given freely during the preparation of these articles by Professor Frank Hoyt and Professor Carl Eckart, of the Department of Physics, University of Chicago. Thanks are due also to Professor James Franck, of the Department of Chemistry, University of Chicago, for his kindness in furnishing information concerning the famous Franck-Hertz experiments.

1. THE THOMSON ATOM

The first theory of atomic structure that had a definite form was offered in 1904 by Sir. J. J. Thomson.[1] His epoch making experiment on the ratio of the charge to the mass of the carriers of negative electricity in cathode rays, based on his assumption that these carriers were particles, had disposed of any hypothesis that they might be anything but particles. The atom contained electrons. Now arose the question as to the number of electrons in the atom. The clue to the answer Thomson[2] found in the scattering of a beam of x-rays passing through matter. If e is the charge on the electron, m its mass, c the velocity of light and N the number of electrons per unit volume, then the scattering coefficient σ, he showed, was given by

$$\sigma=\frac{8\pi}{3}\frac{e^4}{m^2c^4}N.$$

This scattering coefficient had been experimentally determined by Barkla, the value of

[1] Thomson, Phil. Mag. **7**, 237 (1904).
[2] Thomson, *The corpuscular theory of matter* (Constable, 1907), chapter 6.

e/m by Thomson himself; the number of atoms per unit volume of the material was known; hence the number of electrons per atom could be computed. From the early determinations by Barkla of the value of σ, Thomson was led to conclude that this number was of the order of the atomic weight. Later measurements of σ gave the number as more nearly half the atomic weight. It is interesting to note that in the case of the lighter elements—up to calcium—this agrees with modern theory. To overcome the mutually repelling forces of the electronic charges and retain the electrons in the atom, the negative charges of the electrons must be balanced by an equal positive charge. Thomson had shown that the mass of the electron is of the order of 1/2000 the mass of the hydrogen atom. It followed that nearly the entire mass of the atom was associated with the positive charge which it contained.

Any acceptable theory of atomic structure had to explain the emission of line spectra. The electromagnetic theory postulated the existence in the atom of elementary particles which were normally at rest, but which on being disturbed would vibrate with the frequencies required to produce the characteristic line spectra of the elements. In view of the much larger mass of the positively charged part of the atom, the assumption was reasonable that it was the electrons which vibrated in the process of emitting radiation.

All these requirements, based on the conclusions from experiment and the principles of electromagnetic theory, were satisfied to a considerable extent by the atom model proposed by Thomson. He described the atom as consisting of a sphere of positive electrification of dimensions of the order of 10^{-8} cm, throughout which the electrons were distributed. Electrostatic forces would hold them in fixed positions. If they were displaced from these equilibrium positions, they would be acted on by a return force proportional to the displacement. Thus they would execute simple harmonic vibrations and would be capable of emitting radiation of a corresponding frequency. Thomson calculated the arrangements of the electrons for some 70 different atoms.

This atom model appears to have been more or less generally accepted for nearly a decade, despite serious shortcomings. It failed to account for the atomic spectra. The hydrogen atom, for example, has one electron, which Thomson's theory placed at the center of the atom. If displaced from this equilibrium position it would vibrate with a certain frequency and would be capable of emitting radiation of only that frequency. Thus the hydrogen spectrum ought to have only one line.

Another objection to this theory of atomic structure resulted from applications of electromagnetic theory to the electron itself. During the early years of the century the possible shapes of the electron interested investigators. In particular, the so-called "contractile" electron described by H. A. Lorentz[3] received much attention. Lorentz suggested that the electron had a spheroidal form, and he derived expressions for the mass of the electron, distinguishing between the *longitudinal mass*, given by the ratio of the applied force to the acceleration produced when the applied force is parallel to the direction of motion, and the *transverse mass*, when the force is perpendicular to that direction. If e is the charge on the electron, a is its radius, c is the velocity of light, β is the ratio of the velocity of the electron to the velocity of light, and m_T and m_L are the transverse and longitudinal mass, respectively, the equations for the mass are:

$$m_L = \frac{2e^2}{3ac^2}(1-\beta^2)^{-1},$$

$$m_T = \frac{2e^2}{3ac^2}(1-\beta^2)^{-1}.$$

These equations tell us that the mass of the electron is a function of its velocity. For values of the velocity of the electron exceeding about one-tenth the velocity of light, they predict an appreciable increase in the mass with increasing velocity. In 1906 Kauffmann[4] measured the mass of the electron for various velocities up to a very high value, and the results of his experiments showed a variation in the mass with velocity in fairly good agreement with the theory developed by Lorentz. This agreement between theory and observation, which was confirmed

[3] Lorentz, *The theory of electrons* (Teubner, 1909).
[4] Kauffmann, Ann. d. Physik **29**, 487 (1906).

later by the research of Bucherer and Neumann on the deflections of fast beta-particles subjected to forces perpendicular to the direction of motion, indicated that the mass of the electron is entirely electromagnetic. By inference, this is true of the elementary positive particle also.

The expressions just cited show that for velocities which are small compared to the velocity of light, the mass approaches a constant value $m_0[=2e^2/3ac^2]$, which is called the *rest mass*. Evidently the radius a of the particle is inversely proportional to the mass. On substituting the accepted values of e, c and m_0, one finds that the radius of the electron is 1.88×10^{-13} cm, while the radius of the positive particle, the mass of which is 1845 times as large as that of the electron, is 1.03×10^{-16} cm. Thomson's atom gave the dimensions of the positive part as 10^{-8} cm, and those of the electron as being much smaller, which was just the reverse of what this theory required.

The final blow that rendered the Thomson model obsolete, despite attempts to revive it by injecting quantization, came in 1912 from the experimental work by Rutherford on the scattering of alpha-particles, which proved that the central positive charge of atoms must occupy a very small space indeed. Calculations based on the Thomson model as to the number of alpha-particles scattered through large angles on passing through a given material deviated radically from observed results. According to these calculations, for instance, the number of particles scattered through an angle of 30° on passing through gold foil of a given thickness is of the order of one in 10^{13} particles. But Geiger and Marsden[5] showed in 1909 that 1 in 8000 particles was deflected through an angle greater than 90° by a thin film of platinum.

2. THE RITZ MAGNETIC ATOM MODEL

An interesting attempt to arrive at an atomic explanation of the laws of spectral series was made by W. Ritz[6] in 1908. He pointed out that the known series laws involve the frequency ν instead of ν^2, as would be expected, since the acceleration is $(d^2/dt^2)[\sin\nu(t-t_0)]$. Thus the forces appear to be proportional not to the position, but to the velocity of the electron, as in the case of motion of a charge in a magnetic field. This suggests the hypothesis that the frequencies in spectral series are generated by purely magnetic forces.

Considering an electric particle of charge e and mass m in a magnetic field of strength H parallel to the z axis, we have, from electromagnetic theory,

$$m\ddot{x}=\frac{eH}{c}\dot{y},\quad m\ddot{y}=-\frac{eH}{c}\dot{x},\quad m\ddot{z}=0,$$

from which

$$x=A\sin\frac{He}{mc}(t-t_0),$$

$$y=A\cos\frac{He}{mc}(t-t_0),$$

$$z=z_0-Bt,$$

where A, B, z_0 and t_0 are arbitrary constants. These equations represent a helicoidal motion—uniform translation parallel to H, superposed on a circular vibration of frequency $eH/2\pi mc$ in the plane perpendicular to H. Ritz assumes that H is due to a molecular magnet of pole-strength μ and length l. Assuming e to be located on the axis of the magnet produced a distance r from its nearest pole, he got

$$H=\mu\left[\frac{1}{r^2}-\frac{1}{(r+l)^2}\right],$$

which gives

$$\nu=\frac{\mu e}{mc}\left[\frac{1}{r^2}-\frac{1}{(r+l)^2}\right]. \tag{1}$$

This equation is similar in type to the formulas for spectral series, such as the one Ritz himself had derived empirically, namely,

$$\nu=R\left[\frac{1}{a^2}-\frac{1}{(n+a+b/n^2)^2}\right],$$

where R is the Rydberg constant, a and b are constants depending on the kind of atom and the series considered, and n takes successive integral values. Ritz considered the similarity in the two equations very significant, since the spectral laws differ so entirely from other known laws.

To show how his magnetic formula would apply in a particular case, Ritz selected the Balmer formula, an equation of the type,

$$\nu=R\left[\frac{1}{a^2}-\frac{1}{(a+n)^2}\right].$$

[5] Geiger and Marsden, Proc. Roy. Soc. London **82**, 495 (1909).

[6] Ritz, Ann. d. Physik [4] **25**, 660 (1908).

In the case of the Balmer series, $a=2$ and $n=1, 2, 3, \cdots$. Suppose that in Eq. (1) we let $r=as$, and $l=ns$, where a and n have the values just given, and s is a constant. This substitution would give

$$\nu=\frac{\mu e}{s^2mc}\left[\frac{1}{a^2}-\frac{1}{(a+n)^2}\right]. \tag{2}$$

It is evident that Eq. (2) is identical with Eq. (1) if $R=e\mu/s^2mc$. Since l is the length of the molecular magnet, and n is an integer, it appears that this molecular magnet, the length of which is a multiple of s, must be formed by placing n magnets of length s pole to pole. Ritz showed by electromagnetic theory that these molecular magnets might well be electrons, possibly of a cylindrical shape, with their charges distributed uniformly over the surface, and spinning about their own axes. Considerations of stability precluded the possibility of an orbital motion about a center. If such a motion did occur, Ritz thought that one could ascribe to it only a perturbation effect which might result in a broadening of the spectral lines. The spinning electrons would not radiate energy, and this was a prime consideration in all atomic theory prior to Bohr.

If the length of the elementary magnet is changed and r is varied properly, Eq. (1) can be reduced to

$$\nu=R\left[\frac{1}{(a+\alpha)^2}-\frac{1}{(n+\beta)^2}\right], \tag{3}$$

where α and β are constants that depend on the kind of atom. This is the Rydberg formula. Ritz now argued that the atomic forces must have a similar effect on both poles, so that if one found a series given by, for instance,

$$\nu=R\left[\frac{1}{(1+\alpha)^2}-\frac{1}{(n+\beta)^2}\right], \tag{4}$$

it was reasonable to assume that one should also find a series defined by

$$\nu=R\left[\frac{1}{(1+\beta)^2}-\frac{1}{(n+\alpha)^2}\right]. \tag{5}$$

Now, Eq. (4) gives the principal series and Eq. (5) the sharp series of the alkali metals. If in these equations n is set equal to unity, the numerical values of the frequencies are the same. This is equivalent to saying that the first line of the principal series in the spectra of the alkalies is also the first member of the sharp series, a fact which had been discovered 12 years before by Rydberg and also by Schuster.

If, in Eq. (3), a is allowed to take successive integral values as well as n, an entirely different series is predicted for each value assigned to a. Ritz pointed out that the hydrogen spectrum should have other series besides the Balmer series, and in the succeeding decade four more series of hydrogen were discovered. In another paper which appeared at the same time,[7] Ritz predicted also that the spectra of the alkalies should show many more series besides the sharp, principal and diffuse series known at that time. The eventual discovery of the so-called "combination sharp series" and "combination principal series" verified this prediction as well. This was the first formulation of the now famous Rydberg-Ritz combination principle.

Ritz further calculated from electrodynamic considerations the effect upon the frequency of the lines of adding a constant magnetic field to the original magnetic field of the atom, and suggested that expressions for the splitting up of the lines observed in the Zeeman effect might be derived. This proposed model of Ritz's was not developed; but in 1915 it was resurrected and a more or less serious attempt made to use it. This will be discussed in a later article. It is interesting to note, in concluding, that Ritz pioneered the idea of a spinning electron as early as 1908.

3. THE NUCLEAR ATOM

The first attempt at constructing a nuclear atom was made in 1904, when Nagaoka[8] submitted a tentative sketch of an atom model. He called it a "quasi-stable system." It consisted of a large number of electrons equally spaced in a circle, with a single heavy nucleus at the center. Coulomb's law of electrostatic attraction and repulsion was supposed applicable. The particles were assumed to be oscillating either radially or normally to the plane of the orbit, while maintaining constant speed in the circular orbit.

[7] Ritz, Astrophys. J. **28**, 237 (1908).
[8] Nagaoka, Phil. Mag. **7**, 445 (1904).

The charge on the nucleus was much greater than that on one of the electrons, which were also much smaller than the nucleus. Nagaoka did not calculate any frequencies of radiated energy. He suggested the breaking of the ring as a possible cause of radioactive emission.

In 1911 Rutherford proposed his well-known atomic model, which differed essentially from the Thomson model in that the positive charge was concentrated at the center instead of being uniformly distributed throughout the atom. His conception of the actual model may best be comprehended from his own words:[9]

> We shall first examine theoretically the single encounters of alpha particles with an atom of simple structure, which is able to produce large deflections of an alpha particle, and then compare the deductions from the theory with the experimental data available.
>
> Consider an atom which contains a charge $\pm Ne$ at its center surrounded by a sphere of electrification containing a charge $\mp Ne$ supposed uniformly distributed throughout a sphere of radius R. e is the fundamental unit of charge, which in this paper is taken as 4.65×10^{-10} E.S. unit. We shall suppose that for distances less than 10^{-12} cm the central charge and also the charge on the alpha particle may be supposed to be concentrated at a point. It will be shown that the main deductions from the theory are independent of whether the central charge is supposed to be positive or negative. For convenience, the sign will be assumed to be positive. The question of the stability of the atom proposed need not be considered at this stage, for this will obviously depend upon the minute structure of the atom, and on the motion of the constituent charged parts.
>
> In order to form some idea of the forces required to deflect an alpha particle through a large angle, consider an atom containing a positive charge Ne at its center, and surrounded by a distribution of negative electricity Ne uniformly distributed within a sphere of radius R . . . .

Using this model, Rutherford computed the number of alpha-particles per unit area striking a screen at an angle of deflection ϕ to be proportional (*i*) directly to $\operatorname{cosec}^4 \frac{1}{2}\phi$; (*ii*) directly to the thickness t of the scattering material, for small values of t; (*iii*) directly to $(Ne)^2$, where e is the charge on the electron and N is an integer depending on the atom; and (*iv*) inversely to the square of the initial kinetic energy of the particles. These predictions were completely verified by the experiments of Geiger and Marsden.[10]

[9] Rutherford, Phil. Mag. **21**, 669 (1911).
[10] Geiger and Marsden, Phil. Mag. **25**, 605 (1913).

This established the claim of the model to serious consideration, despite objections to it as regards stability. It was impossible to explain how equilibrium could be secured, if the electrons were at rest, by the operation of electrostatic forces alone. The electrons would repel one another with forces much less than those which would attract them to the nucleus, and would fall into the latter. Giving the electron circular orbital motion, similar to that of the earth about the sun, for example, does not remove the difficulty. If the electrostatic attraction Ee/r^2 of a nucleus of charge E for an electron of charge e at a distance r is just balanced by the centrifugal force mv^2/r, mechanical equilibrium results. But the electromagnetic theory demands that such a revolving electron, being subjected to a constant centripetal acceleration, should radiate energy. This energy can come only from the energy of the system, which will therefore decrease, thus causing the electron to approach the nucleus by a spiral path and to emit radiation of constantly increasing frequency. This is in contradiction to the observed sharpness of spectral lines.

These difficulties made it necessary to cast about for a new approach. In 1912 the first attempt was made at applying the quantum theory of Planck to the nuclear atom; a previous discussion by A. E. Haas[11] in 1910 of the significance of Planck's constant based on Thomson's atom will be mentioned in Section 5.

4. THE QUANTUM THEORY

In the first of his epoch-making papers Bohr[12] pointed out that the inadequacy of the classical electromagnetic theory in the discussion of the behavior of systems of atomic dimensions was generally admitted. It had been found necessary, in explaining diverse phenomena aside from those of thermal radiation, to depart from the strict classical electromagnetic theory and to introduce into the laws describing these phenomena the quantity that had become familiar to physicists as the *Planck constant*.

The origin of the quantum theory of radiation proposed by Planck[13] lay specifically in the

[11] Haas, Jahrb. d. Rad. **7**, 261 (1910).
[12] Bohr, Phil. Mag. **26**, 1 (1913).
[13] Planck, Verh. d. D. Phys. Ges. **2**, 237 (1900); Planck, Ann. d. Physik **4**, 553 (1901).

failure of the classical electromagnetic theory to account for the phenomena observed in the study of blackbody radiation. Since an adequate presentation of the genesis of the theory and the derivation of Planck's equation is beyond the scope of this paper, a brief outline merely of the salient points will be attempted.

An ideal blackbody is one that absorbs all radiation incident on it. If the energy of the radiation emitted by a blackbody is plotted as a function of the frequency of that radiation, characteristic curves are obtained at every temperature. The intensities associated with the frequencies of this radiation differ in a manner that was the subject of much investigation just before the turn of the century. It was found that the spectral distribution of the radiation intensities varies with the temperature of the blackbody emitting the radiation, but is independent of its material composition. The well-known Stefan-Boltzmann law, Wien's displacement law and the Rayleigh-Jeans law resulted from attempts to reconcile theory and observation. The method of calculating the intensity distribution was based on the assumption that the radiation is emitted because the particles composing the blackbody vibrate as linear harmonic oscillators with many different frequencies, and it is the variation in the relative intensities associated with these different frequencies that caused the differences in intensity observed in the blackbody spectrum. But all attempts to obtain an expression for the distribution of intensities among the different frequencies led to the prediction that the radiation of very high frequencies in the blackbody spectrum should be extremely intense, whereas the actual intensity associated with these frequencies approaches zero.

In 1900 Planck proposed a startling deviation from classical ideas: it might be admitted that the elementary oscillators possessed all possible frequencies of vibration, but not all energies of vibration. Planck assumed that the energy of each oscillator must be an integral multiple of the quantity $h\nu$, where h is a universal constant and ν is the frequency of the oscillator in question. He called $h\nu$ a *quantum of energy*, and h the *quantum of action*.

It was impossible to reconcile this assumption with the theory that light is a wave motion. The classical conception of a wave carries with it the inevitable assumption of a continuous distribution of energy. On the basis of a corpuscular theory of light, however, quantization of light energy could be easily conceived. Einstein[14] realized this, and followed Planck's lead, when in 1905 he applied the quantum theory to the explanation of photoelectric phenomena. His well-known photoelectric equation, $\frac{1}{2}mv^2=h\nu-\omega_0$, was verified by experimental work done by Ladenburg in 1907 and by Millikan in 1916.

This second triumph of Planck's theory was followed very shortly by another. In 1907, Einstein[15] again used the quantum theory to explain specific heats; the classical theory had failed to account for variation in atomic heat with temperature, whereas the equation set up by Einstein, and developed by Nernst and Lindemann,[16] fitted the experimental data well. It was an obvious step, therefore, to try to apply this theory to the explanation of spectral radiation and to atomic structure.

5. EARLY ATTEMPTS AT THE APPLICATION OF THE QUANTUM THEORY TO ATOMIC STRUCTURE

Haas' Quantization of the Thomson Atom

The first attempt at "quantizing" the atom was that made by Haas. In a paper entitled "Der Zusammenhang des Planckschen elementaren Wirkungsquantums mit den Grundgrössen der Elektronentheorie"[17] Haas computed the total energy of the hydrogen atom according to Thomson's model by making use of ordinary mechanical formulas; then he computed $h\nu$ for this atom, and compared the results. If the radius of the atom is a and that of the electron orbit is r, the force with which the electron is attracted to the center of the atom is given by e^2r/a^3, the kinetic energy of the electron is $e^2r^2/2a^3$, and the latter is equal to the potential energy. If r equals a, we have for the kinetic or the potential energy the value $e^2/2a$ and for the total energy the value e^2/a.

[14] Einstein, Ann. d. Physik **17**, 132 (1905).
[15] Einstein, Ann. d. Physik **22**, 180 (1907).
[16] Nernst and Lindemann, Sitz. Preuss. Akad. Wiss., p. 494 (1911).
[17] Haas, Jahrb. d. Rad. **7**, 261 (1910).

To compute the frequency of vibration ν he proceeded as follows. The force acting on a particle in simple harmonic motion is $m \cdot 4\pi^2\nu^2 r$. Equating this to e^2r/a^3, we get

$$\nu = \frac{e}{2a\pi(am)^{\frac{1}{2}}} = \left[\frac{e}{4a^3\pi^2}\left(\frac{e}{m}\right)\right]^{\frac{1}{2}}.$$

Haas used the following values:

$$1.1 < a \times 10^8 \text{ cm} < 2.2$$
$$3.0 < e \times 10^{10} \text{ esu} < 4.7$$
$$e/m = 5.6 \times 10^{17} \text{ esu g}^{-1}$$
$$h = 6.548 \times 10^{-27} \text{ erg sec.}$$

The ratio of e^2/a to $h\nu$ lies between 0.70 and 1.92, with 0.93 as the most likely value. That is, $h\nu$ was about equal to the total energy of the atom.

Nicholson's Theory

The sketchy attempt by Haas at "quantizing" the atom was followed in 1912 by a much more ambitious effort on the part of J. W. Nicholson.[18] In a series of papers he presented an atomic model that must have been highly suggestive to Bohr. In an attempt to explain certain lines occurring in spectra of the nebulas, Nicholson assumed a series of hypothetical elements with the simplest possible types of atom. One of them, which he called "nebulium," was supposed to have an atom consisting of a nucleus of negligible size surrounded by a ring of four electrons each of charge $-e$, equally spaced in a circle, the nucleus having a charge $+4e$. These electrons he supposed were vibrating in a direction normal to the plane of the ring. The energy of the system was calculated from the principles of mechanics, and was found to bear a constant ratio to the frequencies with which the electrons would have to vibrate in order to emit certain wave-lengths. This led Nicholson to think that the atom might be considered from the point of view of the Planck oscillator. To quote from one of his papers:[19]

> Since the variable part of the energy of an atomic system of the present form is proportional to $mna^2\omega^2$, $E/\text{frequency} = mna^2\omega$ or $mnav$, which equals the total angular momentum of the electrons around the nucleus. If, therefore, the constant h of Planck has, as Sommerfeld has suggested, an atomic significance, it may mean that the angular momentum of an atom can only rise or fall by discrete amounts when electrons leave or return.

This is one of Bohr's fundamental assumptions. Bohr himself in his first paper gives credit to Nicholson for the latter's ideas. He points out, however, that the theory does not seem able to account for the laws of Balmer and Rydberg concerning spectral series in ordinary elements; further, that[20]

> . . . in Nicholson's calculations the frequency of lines in a line spectrum is identified with the frequency of vibration of a mechanical system in a distinctly indicated state of equilibrium. As a relation from Planck's theory is used, we might expect that the radiation is sent out in quanta; but systems like those considered, in which the frequency is a function of the energy, cannot emit a finite amount of a homogeneous radiation, for, as soon as the emission of radiation is started, the energy, and also the frequency of the system are altered. . . . Finally, according to Nicholson, the systems are unstable for some modes of vibration.

Today Nicholson appears to have been forgotten. Yet his ideas were nearly as revolutionary as Bohr's, and he seems to have held similar fundamental hypotheses. Jeans in 1914 subjected Nicholson's theory to a thorough critical investigation, and says, in part,[21]

> The sharpness of the observed spectral lines demands that the radius of the ring of electrons should remain invariable, or should have only a definite number of possible values, jumping from one to the other instantaneously, perhaps, as the energy is lost by radiation. Whatever view is taken it is obvious that something quite different from the Newtonian mechanics will be required to explain the motion. Nicholson believes he can find quite distinct evidence of the existence of Planck's quantum from a study of the radii of the different rings, but his work is hardly complete enough yet to admit of abstraction as a finished theory. We may take leave of it with the remark that, in addition to whatever it may achieve when more fully developed, it has probably already succeeded in paving the way for the ultimate explanation of the phenomenon of the line spectrum.

Bohr found the ground for his fundamental assumptions pretty well prepared.

[18] Nicholson, Month. No. R.A.S. **72**, 49, 139, 677 (1911–12).
[19] Nicholson, reference 18, p. 139.
[20] Bohr, Phil. Mag. **26**, 7 (1913).
[21] *Report on radiation and the quantum theory* ("The Electrician" Print. & Pub. Co., 1914), p. 50.

Advanced Instruction and Research in Mechanics

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As scientists we are often called upon to distinguish between cause and effect on the one hand and mere coincidence on the other. May I therefore pose at the outset the following questions?

Is it coincidence that the founding of the École Polytechnique just preceded the beginning of Napoleon's successful army campaigns? Is it coincidence that fundamental research in ship construction was assiduously prosecuted in Britain during the period just before 1900, when the maritime commerce of that great nation held an assured position of world leadership? Is it coincidence that over the last quarter century airplane research at Göttingen and other German centers was heavily subsidized and vigorously pursued and that in this war German aviation has come spectacularly to the forefront? Is there a lesson to be learned here in America from the consideration of such concurrences?

The Place of Applied Mathematics in American Education

Since 1900, America has made gigantic strides in mastering its environment. The progress made in the physical sciences and engineering almost outruns the imagination. Taken as a whole, we have advanced in these 40 years from a third-rate power in scientific research to a first-rate power. It is not necessary to identify for you various sectors of the field of the physical sciences where this country now stands pre-eminent; you can name those in physics and astronomy far better than I. On the other hand, there are sectors where we have lagged woefully behind.

It is to overcome the lag in one of those sectors that the work in mechanics at Brown University was inaugurated. This country is deficient, for example, in the mathematical theories underlying ship construction. We have relied on other countries to do much of the mathematical work upon which progress in the engineering of this and other fields must be based; now we must try to make up for lost time.

The Need for a Program

We have in America some men whom we call isolationists. They were defeated at Pearl Harbor; but the onrush of world events has isolated America in a fashion of which they never dreamed. We have discovered alarming deficiencies in rubber and tin and—just as important—in certain types of technics and of ideas. In a world forever at peace we might rely entirely on other countries both for essential materials and for the cultivation of essential sciences; but under present circumstances there is near tragedy in our deficiencies in basic materials and in our lack of command of some of the basic scientific theories. While we shall renew our cooperation with enemy scientists after the war, surely we will not allow ourselves to be caught again in the predicament of neglecting those sectors of science that are basic to our military safety.

Looking ahead to the postwar period, it appears essential that America should be strong in the whole field of science in order that it may serve as a world center for advanced instruction and research. Latin Americans should come north as well as go to Paris; Chinese and other Asiatic scholars should make America, as well as Europe, their goal; the trickle of Europeans in the direction of America, which began before the war, must increase to a considerable stream. In this way, our institutions can demonstrate to nationals of other countries how persons of divergent origins and cultures can live amicably and contribute mutually to the upbuilding of civilization. Science can thus contribute toward a better understanding among the nations of the world.

The Impulse and the Subsequent Development

Late in 1940 the Committee on Survey of Research in Industry appointed by the National Research Council submitted a report to the National Resources Planning Board and to the President of the United States. Of this report,

Dr. Thornton C. Fry, Mathematical Research Director, Bell Telephone Laboratories, wrote one section entitled *Industrial Mathematics*. The report has been widely circulated and is available as a House Document of the 77th Congress.

In his report Fry points out that the field of usefulness of mathematics is expanding, partly through the development of new industries such as aircraft manufacture, and partly through the incorporation of new scientific developments into industrial research, as in the application of quantum physics to chemical manufacturing and of statistical theory to the control of manufacturing processes. He states further that the need for professional mathematicians in industry is bound to grow as the complexity of industrial research increases, though their number will never be comparable to that of physicists or chemists. There is a serious lack, he says, of university courses for the graduate training of industrial mathematicians; on the other hand, management is becoming keenly alive to the importance of obtaining competent men trained in this field to work among their scientific personnel.

The publication of Fry's report was delayed for months; had he written it on the date of its appearance, he doubtless would have stated his arguments with additional vehemence.

In the meantime there was a conviction at Brown University that America could not avoid war, that physics and engineering and the underlying mathematics were bound to play a leading role in its prosecution, and that steps should be taken to strengthen one of the weakest links in the American scientific chain. With the support of the ESMDT program of the U. S. Office of Education and the Carnegie Corporation, a 12-weeks' school was set up in the summer of 1941. There were 60 in attendance, the main program centering around such topics in mechanics as elasticity, fluid dynamics and partial differential equations of physics. In each of these subjects there was given the equivalent of a year's course, and in addition, there were research seminars. The mathematical preparation of the participants ranged from that of a second-year graduate student to that of a mature investigator.

The faculty for this and succeeding sessions was made up almost exclusively of men from continental Europe. This is in large part due to the dearth of Americans trained in this field. Several of the great European leaders had given their allegiance to this country; some of them lent their talents to the establishment of the new school. In particular, Richard von Mises, the distinguished founder and editor of the *Zeitschrift für angewandte Mathematik und Mechanik*, formerly Director of the Institute for Applied Mathematics at the University of Berlin, gave assistance through advice and participation in the instruction.

To study the experiment of the summer of 1941, an Evaluating Committee was appointed consisting of the following eminent scholars and administrators: Marston Morse, of the Institute for Advanced Study, President of the American Mathematical Society; Mervin J. Kelly, Research Director of the Bell Telephone Laboratories; George B. Pegram, Dean of the Graduate School, Columbia University; Theodore von Kármán, Director of the Aeronautics Laboratory, California Institute of Technology; Warren Weaver, Director for Natural Sciences, Rockefeller Foundation. In its report the Committee went carefully into the historical setting of the present status of mathematics in America. Among its observations is the following:

> Thus there has been in American mathematics since 1900 a marked tendency to emphasize pure mathematics. The success of this development is a great source of national strength and should be a cause for national pride. But it is highly unfortunate that in our enthusiasm for pure mathematics, we have foolishly assumed that applied mathematics is something less attractive and less worthy. For in the history of science it has universally been true that the "pure sciences" and the "applied sciences" have been vigorous and prosperous almost exactly to the degree that they have highly regarded each other and been concerned with each other. It is obvious that, in the long run, pure mathematics and applied mathematics ought to be in the closest relationship of mutual respect, parallel development, and continuously stimulating interaction.

The Committee discussed methods of reaching the desirable objective and included as a part of its report the following:

> It would also clearly be advantageous, however, if a larger number of persons trained as mathematicians would become interested in engineering and other

> problems in which their mathematical skill could be put to effective use. Indeed, perhaps the most effective way in which such mathematicians, who turn their attention to problems of applied mathematics, can be useful is in the mathematical instruction of the larger group of engineers and others who need to be trained to use mathematics with understanding, skill, and insight. A smaller number of applied mathematicians will be employed, as such, in industry and business. From a still smaller number we may expect new mathematical developments, arising out of the practical problems on which they work.

In discussing the means for remedying the present situation the Committee commented that it did not believe that a sufficiently prompt and effective improvement would result from the ordinary evolution of educational methods. Something striking and forceful was required.

The report of this Evaluating Committee emphasized the need for a long-range program: (1) to prepare teachers of mathematics in scientific and engineering schools; (2) to furnish research personnel for government agencies and for industry. Less than two months after the report was made, the blow fell at Pearl Harbor and the orientation of our program was necessarily shifted to a shorter range in order to aid in the war effort.

During the academic year 1941–42 there were 30 persons in residence. Some stipends were available from funds generously furnished by the Carnegie Corporation; instruction and research were continued in a more fundamental manner than was possible in a summer session.

During the summer of 1942 a somewhat more ambitious program was attempted. One hundred ten students were selected and courses were given of three different grades, the most elementary being designed for first-year graduate students who had a good background in mathematics as well as in either physics or engineering. For the 45 enrolled persons who possessed the doctorate there were advanced courses, seminars and research direction.

During the present year the school has 40 persons in residence and a number doing part-time work. Through the generous support of the ESMWT and the Carnegie Corporation, the high-grade program is still developing. The Rockefeller Foundation has supplied funds for fellowships which enable eight men with doctor's degrees in applied mathematics to carry on research, as well as for a considerable number of men with lesser preparation to participate in the program as students.

For the remarks that follow I have drawn heavily on Fry's report and on the unpublished report of the Evaluating Committee.

Why has America Neglected Applied Mathematics?

It would be difficult to trace the reasons why applied mathematics has not flourished in a country that reputedly is so practical. Undoubtedly it is in part due to the influence of the men who around 1900 brought back from Europe a flaming enthusiasm for fundamental rigor in mathematical thinking. The early part of this century has been a period analogous to the Greek era when logic was foremost and intuition was thrust into the background. The great Gibbs had left no school to carry on his epoch-making investigations, and there was no outstanding figure in applied mathematics around whom a group could gather. There are institutions that have maintained resolutely, over a long period, the tradition of mathematics as applied to engineering, notably the University of Wisconsin and the Massachusetts Institute of Technology; and there are others now following the same course. But it is fair to say that pure mathematics has far outstripped applied mathematics in this great country.

We lead the world in many fields of pure mathematics. Moreover, although it is probable that clear superiority has not been established, we can hold our own in such sectors of applied mathematics as thermodynamics, electrodynamics and statistics. On the other hand, the field that would be designated *theoretical mechanics* by the engineer and *applied mechanics* by the mathematician has been seriously neglected.

Relation to Adjacent Fields

The engineers and the engineering societies have not failed to note the deficiency in this sector and have encouraged and welcomed contributions to the field of applied mathematics. For example, in the American Society of Mechanical Engineers there is an important Division

of Applied Mechanics. The various American journals of physics have been hospitable to many types of papers in applied mathematics. But the contributions have come chiefly from the physicist and the engineer rather than from the mathematician, and the time has come for the mathematician to assume his share in the development.

Here in America there has been too often a lack of understanding between the engineer and the mathematician; each has shown impatience with the attitude of the other. This unfortunate situation is now happily in the process of rectification. The engineer is primarily concerned with the end result, the mathematician with the means by which the result is achieved. To be able to translate the engineering problem into terms of data that can be dealt with mathematically not only takes wide training and experience, but requires a special insight which is none too common. The number of men with such insight will always remain limited. We can increase the present number but, while many young men may be influenced to choose this career, the proportion of those who will break new paths through the intricate mazes of material is extremely limited. Nevertheless, such scientists must be found.

An applied mathematician must deal with concrete detail instead of with abstract principles. His problem is set for him and he cannot choose the conditions imposed. He can give counsel and assistance to those engineers who are involved in practical detail; he can appraise the problem in terms of science; and, conversely, he can translate abstract language into terms easier for application to industry. Some mathematicians cannot work under these conditions at all; some can do so only by patience and hard work.

The mathematical engineer (if we may be allowed to coin such a phrase) must be able to appraise experiment and decide whether the line of attack on an engineering problem lies in experiment or in mathematics or in an alternation or combination of these methods. His contribution must be in those aspects of the investigation in which advanced mathematics can lend a hand.

As one example cited by Fry, let us consider the phenomenon in wings of airplanes known as *flutter*. It is a self-excited vibration which will throw a plane out of control and may even result in a breakdown of the wing itself while in flight. Here the problem is to make sure in the design that the critical speed at which flutter will occur is higher than any at which the craft will be flown. Fortunately the fundamental mathematical theory was worked out some years ago by Theodorsen so that not only can the critical speed be foretold, but the design may be so modified that flutter is impossible in the contemplated speed range.

To cultivate applied mathematics is to forge more powerful tools for the problems that confront engineers and physicists and to train young men to wield these tools. If we stop to consider this problem of cultivation, we will see that it is a tremendous one and that a program such as that inaugurated at Brown University can serve only as one small element in the solution. But an impetus is being given which, we hope, will in the long run have far-reaching effects.

The Program

The ideal training of an applied mathematician will include a good deal of physics and some high-grade engineering. In his mathematical repertory, he will have vector and tensor analysis, differential geometry, theory of functions of a complex variable, theory of differential and integral equations, orthogonal functions, calculus of variations, and so forth. The physics courses should include the old-fashioned fundamentals of heat, sound, light and electricity; special attention needs to be given to mechanics in the larger sense.

Aerodynamics draws heavily on such subjects as potential theory and conformal mapping; questions of ship design lead to problems in the calculus of variations; the study of gravitational and electric fields, as applied to prospecting for oil, calls for a thorough knowledge of the Newtonian potential and of complex variable theory; improving the efficiency of relays brings in the calculus of variations; electric circuit theory involves matrices and analysis situs; the study of elastic and plastic properties of materials leads to linear and nonlinear differential equations. One could multiply examples.

Originally it was intended that instruction in the school should extend over three years, thus giving a substantial training equivalent to that for a Ph.D. degree. One year might be spent in another institution or in an industry. In the present emergency, however, it is inevitable that the great bulk of the students will be in residence for shorter periods.

Activities

The activities of the school may be discussed under two heads—instruction and research—though in the present organization these are inextricably knit together. The instruction is centered in a core which may be called *theoretical mechanics*, but this is surrounded by courses in other fields of applied mathematics, including some phases of theoretical engineering. The extensive distribution of lecture material in mimeographed form would classify as instruction in the broad sense. Lectures on special topics by visiting specialists constitute an important feature of instruction, while conferences on topics of current research form one of the links between instruction and investigation. On the research side, the papers prepared under the leadership of the staff could easily be classified as a part of the instructional program. The new journal of applied mathematics will supplement these activities.

Mechanics

As I have used the term, *theoretical mechanics* includes advanced work in fluid mechanics, elasticity, plasticity, aerodynamics, theory of vibrations, theory of structures, and so forth. This field is of rather vast proportions and is growing apace. We are fortunate that some of the mathematical work of the Russians done during the past five years can be included in this instruction. Remarkable people, these Russians, as we are learning from their many activities and to our immense satisfaction.

As an example of the service being rendered by the school, we may cite the topic of elasticity. Love's textbook was ample for its day, but new ideas and methods have been gradually introduced and now we have the latest developments from Russia. The mimeographed notes of Sokolnikoff's course in elasticity incorporate the most significant elements of the new material in this particular field. They constitute a real advance over any textbook now in existence, and it is hoped that within a year a printed edition will be available. The same is true also in some other fields of mechanics, such as nonlinear vibrations, where the latest advances are included in the material for the course.

Related Courses

It is the policy of the school each semester to give students opportunity to work in some field of applied mathematics that would not be classed as mechanics. In the summer of 1942, Doctor Schelkunoff, of the Bell Telephone Laboratories, lectured on electromagnetic waves, and these lectures will soon appear as a treatise. During the present academic year, Professor Brillouin is giving work on thermodynamics. An advanced course in geometrical optics is being contemplated for next summer. Other fields are due for similar treatment later.

The partial differential equations of physics are fundamental for much work not only in mechanics but in other sectors of applied mathematics. It is therefore necessary to give a broad and thorough course in this field. As prerequisites, students must have had advanced calculus and the theory of a complex variable.

Since computations play an important role in so many of the applications, it is necessary to develop the theory of calculations to the point where an intelligent attack on a particular problem involving extensive computation can be made. A year course on numerical and graphical methods is now being given for the second time; we hope that eventually a book will be published which will extend our horizon in this area.

The school is sponsoring some courses that lean toward engineering. Naturally they are more mathematical than would normally be the case in a graduate school of engineering. In this connection, we may mention theory of flight, theory of structures with special reference to problems in aircraft design, and hydrodynamical theory of propellers.

After recounting these divergences, it should be reiterated that instruction is *centered* around the various aspects of theoretical mechanics.

Special Lectures

One feature of the program is the provision for special lectures or series of lectures. A score of leaders have spoken at Brown. These addresses include the practical aspects of the application of mathematics to engineering problems as well as the theoretical aspects; some of these addresses contain new material which we are publishing; others have been more general reviews of what is already in the literature. One of the features of the current semester is a series of 15 lectures on nonlinear mechanics by Friedrichs, Stoker, LeCorbeiller and Levinson. These contain the results of current research in this highly significant field; the lectures are being duplicated for distribution. In this connection, we should mention the cooperation of the school with Dr. Nicolas Minorsky of the David Taylor Model Basin, which will result in making available to mathematicians and engineers some of the very recent research in this field done by Russian mathematicians and not until now available except in that language. In the next semester there will be a series of lectures on exterior ballistics in which some of the recent developments will be presented by experts now engaged in research in this field.

Mimeographed Material

Each of the four series of lectures given in the summer of 1941 was put into mimeographed form. Without any special advertising, more than 500 copies of each have been sold to individuals and libraries. Several later series of lectures have been made available in similar fashion.

Research

While the main function of the school is instruction, the nature of advanced work is such that this must go hand in hand with research. There are six or eight men holding the Ph.D. degree now in residence in a capacity similar to that of National Research Fellows. Since 1941 approximately 20 investigations have been completed and written up; others are under way. There is a group of papers that are chiefly of theoretical interest, and another group of immediate application. Some of these papers are being published; others, because of their restricted character, must await the close of the war.

Conferences

From time to time, the school plans to bring together a group of leaders in some special field where research is active. In a three-day conference on nonlinear vibrations held during the summer of 1942 a score of persons active in this field came together for lectures and discussions which we confidently expect to result in the extension of the field. Some of the material presented at that time is to appear in published form.

A New Journal

Discussion of the need for a journal devoted specifically to the field of applied mathematics and filling the gap between purely engineering journals and purely mathematical ones has been going on for a number of years. There is little doubt that a properly organized publication will have a profound effect on the development of scholarship in an area that has received less attention than it justly deserves. That there are difficulties in the way of inaugurating a journal at this time is apparent; but on the other hand, attention is now focused on the importance of the role played by mathematics in technological development and many scientists will welcome the new venture. A publication to be known as *Quarterly of Applied Mathematics* and of a national (and international) character is being inaugurated early in 1943, under the sponsorship of the school. Close cooperation with journals in related fields is assured in advance. The names of the editors—Dryden, Fry, von Kármán, Prager, Sokolnikoff, Synge—are a guarantee of high quality; there will be a Board of Collaborators of equal distinction.

Organization and Future

The school is run as a separate department in the Graduate School of Brown University and has a small faculty of its own besides enlisting some members of the departments of mathematics and engineering. The members of the faculty are selected as the best persons available in their fields. There is an Advisory Committee

which helps in shaping policies, in selecting fellows, and so forth; this consists of Thornton C. Fry, of the Bell Telephone Laboratories; Marshall H. Stone, Chairman of the Department of Mathematics, Harvard University, and the new president of the American Mathematical Society; and Theodore Theodorsen, Chief of the Physical Research Division, National Advisory Committee on Aeronautics, Langley Field.

The superb mathematical library of Brown University forms an excellent background for the instruction. The international abstract journal, *Mathematical Reviews*, is edited at the University and is supplemented by an extensive microfilm service.

Plans for the summer program of 1943 are well along, and a study of the needs for subsequent semesters is being made. All institutions face uncertain futures, but Brown University is wholeheartedly committed to carrying on a program in applied mathematics, provided the way can be found to continue it on a high level.

What the Former Participants Are Doing

Of the nearly 200 persons who have enrolled at one time or another in the school, 30 have gone into research in government agencies such as Langley Field, David Taylor Model Basin, Naval Research Laboratory, Underseas Detection Laboratory, National Bureau of Standards, Watertown Arsenal; 10 are engaged in research in industries connected with the war; 20 others are continuing as engineers in industry. The remainder are instructors or students in colleges. Of the instructors now in other colleges, a dozen or more are actively engaged in research on problems of applied mathematics which were begun at Brown University.

Engineering Training in the Future

In their magnificent accomplishments American engineers have shown initiative and ability of a very high order. Insofar as mathematics and physics are handmaidens of engineering it is doubtless true, however, that much remains to be done in giving maximum efficiency to their effort. In other countries the bulk of the engineers get a year or two of scientific training beyond what American students get in their four years. The number in this country who take graduate work in engineering is increasing and doubtless will continue to do so. At least a small proportion of them should specialize on the mathematical side.

Some day we may expect that much better training in mathematics and physics will be given to picked groups in our high schools, thus affording young people opportunities for excellent basic training in the sciences that are already available in many European countries. If the time should come when as much attention is given by high school authorities to the superior students as is now given to the decidedly inferior, great progress in this direction could be made. Such students can then obtain a superior college training and come to schools, such as the one we are describing, with far better preparation.

Let us return for a moment to the questions posed at the beginning. Or shall I allow you, after patiently reading this article, to propound your own speculations as to cause and effect *versus* coincidence?

PRACTICALLY all basic inventions affecting naval, military and aviation technology have been civilian in origin (as witness the rifle with interchangeable parts, the submarine, the machine gun, the tank, the airplane, poison gas, sound detection devices for submarines and airplanes, and most of the metallurgical discoveries which have affected armor and armor-piercing devices). The adaptation of many of these inventions to purely military purposes has, of course, been partly the work of civilians and partly the work of uniformed specialists.—EDWARD MEAD EARLE, an authority on military history, quoted by MARSTON MORSE, *Sci. Mo.* **56**, 51 (1943).

The Physicist in the New World

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"THE old world is dead; the future lies with those who can most successfully turn their backs on that world and face a new one with understanding, courage and imagination." This is the conclusion and clarion call of E. H. Carr's *Conditions of Peace*,[1] a wise and scholarly treatise of the present world revolution, hailed by some reviewers as the most important book published in England during the past year.

Professor Carr does not shrink from prophecy. Since most physicists believe in indeterminacy, and some are willing to extrapolate it to economics, politics and ethics, it seems appropriate to quote also the more conservative Geoffrey Crowther who says, in the *London Economist*, "The need is not for a break with the past but for a return to the native tradition of clear thinking and courage, of lucidity and daring, of bold action for moderate ends."

Perhaps the old world of the physicist is not dead, but who will question the existence of new and critical problems which confront the physicist of today and tomorrow? Who will question the need for "understanding, courage and imagination," for "daring" and "bold action"?

We physicists have a prominent role to play in this changed, if not new, world. The war has called us from our cloistered cells and basements —many to the interesting and important technological problems of research and development in modern warfare; and many others to the no less important training program in phases of applied physics, such as radio, electronics, aerodynamics, meteorology and acoustics. We are working today in close league with engineers and men of war; we are more intimately a part of the economic, political and military structure of society than ever before. Physics as a profession is a large beneficiary of these associations; its prestige is improved; it receives larger public, if not private, subsidies for fundamental as well as applied research; and the relative economic status of the physicist is certain to improve. We are getting as much as we are giving. The degree to which we deserve these benefits will depend not only, or even primarily, upon the extraordinary nature of our discoveries and inventions, but even more upon the extent to which we plan and guide our discoveries and inventions for the welfare of mankind.

Man has failed to adjust himself to the complex environment derived from the relatively recent discoveries of physical science. It is far more important that we assist in making the necessary adjustment than that we participate in making the environment even more complex. The environment undoubtedly will become increasingly complex—the impetus to discovery will take care of that. But the imperatively needed social adjustment to these discoveries will be furthered if we continue to foster many of the new associations and responsibilities the war has imposed upon us. This means that we must be devoted to the problems of human welfare when peace is restored as we now are to the urgent problems of technological warfare.

In order to attain this worthy objective, physics must become more than a source of new mechanical technics and gadgets. It must, I believe, contribute consciously to the science of value, to culture, to the art of better living. This is a large order. What can we do about it?

I believe we can do a great deal. My faith in this belief arises largely from my experiences and observations in the field of acoustics. The Acoustical Society of America owes its existence, in part at least, to a divergence of views that existed among physicists, especially in the nineteen twenties. The American Physical Society did not appear to provide a suitable environment for the development of modern acoustics which then was extending into such fields as communications, architecture, physiology and music. There were divergent views even among those who organized and formed the governing policies of the Acoustical Society: some contended that it should be primarily a physics society; some that it should be an engi-

[1] Published recently by Macmillan. Mr. Carr is Professor of International Politics, University College, Wales.

neering society; and others that it should encompass both, keeping the fundamental and applied aspects of acoustics together. Fortunately, this third view prevailed. The Acoustical Society has enjoyed a wholesome growth; its interests are closely articulated with physics and engineering on the one hand and with the economic and cultural phases of society on the other. The Society's governing policy of extending its interests in many directions, and especially in applied and cultural fields, is one that other branches of physics can emulate with much profit—it is a policy that will help make a broad knowledge of the methods and achievements of physics an indispensable part of a liberal education.

The American Institute of Physics has also been an effective agency in encouraging extensions of the various branches of physics into our contemporary economy and culture; this part of the Institute's program, it seems to me, is expecially worthy of the support of all physicists.

Academic and industrial research in many fields of acoustics is proceeding along lines that contribute to economic and cultural values. Architectural acoustics, atmospheric acoustics, the physics of normal and impaired hearing, the improvement of existing and design of new musical instruments, and the reduction of industrial and city noise are typical research projects in this category—projects to which many of us yearn to return as soon as our score with the dictators is settled. There are many difficult and unsolved problems associated with the five projects just mentioned which await the labor of competent physicists. Professor Philip Morse in his *Vibration and Sound* has furnished us a good example. Quoting his own words,

> It is not such a far cry from auditorium acoustics to second quantization: yet the methods used above [in Morse's book] to analyze the behavior of sound in rooms are quite similar to the methods Dirac used to predict the existence of the positron three years before its experimental discovery. This similarity is an interesting example of the unifying influence of theoretical physics.

Morse's contribution in this one field has thrown new light on the approaches to many important, but heretofore obscure, problems in architectural acoustics, and especially those concerned with music rooms. The solution of such problems will contribute much to human welfare and, incidentally, the technics acquired, if and when necessary, can be made to serve the needs of war.

The theoretical physicist applies the methods of second quantization to auditorium acoustics and, quite majestically, normal modes of vibration, reverberation formulas and even sound absorption coefficients take on elegance and a degree of precision heretofore unknown. But sometimes physics works the other way as, for example, when the calibration of a reverberation room led to quantum phenomena associated with molecular collisions.

The unsolved problems in the single field of atmospheric acoustics are sufficient—are difficult and important enough—to keep a dozen physicists busy and happy for the next 20 years. "Simple, banal stuff," I can hear some physicists say. "Propagation of a wave motion in a continuous, homogeneous, isotropic medium. Introduce determinate boundary conditions, and there you are." But you aren't—and the medium is not continuous, homogeneous and isotropic; and the boundary conditions are simple only in some peoples' heads. Rayleigh gave us a good start on this as on so many other problems, but he also recounted many anomalies, obscurities and mysteries which today are not understood, even sufficiently for the simplest technical applications. Let me illustrate the nature of one of these problems. Set up in a quiet open space a source of sound having a frequency of about 8000 cycle/sec, and measure the intensity of that sound at a distance of about 100 m, using for the detector a microphone, an amplifier and an alternating current meter that can follow rapid fluctuations in the current. Even in the quiet calm of a windless night the intensity of the sound will vary quite randomly over a range of five- to tenfold. I mention this enigma at this time because if you can solve it you will have made a significant contribution to a technological problem that likely will face us in the next world war. And if you solve these problems in atmospheric acoustics, you will find equally enigmatic and fascinating ones in the ocean.

But it is in the realms of hearing and of music that the acoustical investigator of the future can

make the most worthy contributions to culture. Fletcher, Davis, Stevens and others have pried into the secrets of the ear and its auditory apparatus, and not without success; but much remains to be done, especially in contributing toward the amelioration of impaired hearing. New musical instruments are evolving from electronic devices; ultimately they should be better than existing ones, and with better instruments there should follow better music. Here indeed several disciplines, including physics, can unite in research that offers much to intensify the good in man.

There are similar problems in other fields of physics—in optics, in thermodynamics, in biophysics, in nuclear and radiation physics—the solution of which would enrich living and improve the prestige of physics as a humanitarian profession. Among the many research projects in these fields which offer immediate benefits to mankind are electron microscopes, illumination of buildings, and streets and even street signs, the physics of normal and impaired vision, neuroelectricity, photosynthesis, applications of probability technics to nearly all fields of worthy scientific endeavor, including many to which physicists have contributed.

I know some physicists will argue that although these research projects are vital to man's welfare, they are not academically appropriate in the domain of physics research. They affirm that such practical projects lie in engineering, physiology, medicine and other domains outside of physics. The same objections are familiar to those who have worked in acoustics during the past 20 years. I do not wish to belabor this old argument. I merely contend that these admittedly borderline research projects have a better chance of successful fruition if the physicist participates in them than if they are relegated to less exact disciplines.

The physicist in the new world should not shun his responsibility in economic, political and social matters. Perhaps he cannot solve the shifting and illusive problems of money and credit, but I believe he should join hands with the economist in the attempt. There are many places in municipal, state and federal administration where he can serve in the public interest. Read the building and safety code for the city in which you live; you probably will recognize the need for technical service of a type you can well render in revising the code and also in administering it. Heating, lighting, plumbing, plastering, new building materials, resistance to earthquake shock, fireproofing, soundproofing, electric appliances, wood preservatives (as against termites), waterproofing of concretes and stuccos and construction of air-raid shelters and alarm systems—these are typical matters within the jurisdiction of a building and safety department. Technological advances affecting these matters pose problems that call for expert handling, often in domains where the trained physicist is able to give wise counsel. Communications, transportation, public utilities, conservation of natural resources, substitute materials for rubber, tin and other essential imports, and innumerable problems in modern warfare will make increasing bids for the services of the physicist. We should heed these bids, ever preparing ourselves for the greater public service we shall be called upon to perform.

In the new world, science should assume a greater responsibility for the uses of her discoveries than she has done in the past. This, of course, will not stop evil inventions, but if benevolent applications and inventions are actively encouraged and actually pursued by the discoverers, there is hope that some evil will be overwhelmed by the preponderance of good. In a world at war, or likely to be at war again in the next generation, we cannot ignore the applications of our discoveries and technics to the defense of country and civilization; indeed we should do everything possible to unite all nations of good will and provide this coalition with the inventions, instrumentalities and powers necessary to guarantee world peace. If this can be accomplished, we should then be able to divert much of our research effort from projects that serve the interests of war to those that deliberately aim at making a better world.

Finally, the teaching of physics—a subject that should be taught to all who seek a liberal education—is the chief responsibility of most of us. This teaching will be improved, I am convinced, by increasing the emphasis on the utilitarian aspects of physics. For many years I

have followed a simple rule in selecting the subject matter for the undergraduate courses I have taught: the subject matter must have both disciplinary and utilitarian value or it is not admitted to the syllabus for the course. Practical knowledge can be acquired without sacrificing the development of mental discipline, which of course comes first in all good teaching. The instructional policy of combining the practical with the academic has borne good fruit, if I may judge from statements that have come to me from many former students. One such statement came from an Army officer a few days ago. He said, "You seemed to sense in the classroom that the 'punk' sitting there on the front row was interested in making a living." I believe, more than ever before, that our instruction in physics has suffered in that we have trained too many students to be our assistants and disciples in the university laboratories, and too few to take important responsibilities in the practical world, and certainly too few to be independent scholars, thoroughly trained in fundamental and applied physics.

Physics, especially in the universities, has stayed too aloof from engineering, and engineering has strayed too far from physics. The war, as well as industry, has brought physics and engineering into a mutually beneficial relationship. Physicists should seek to extend and improve these relations, not only in the field of engineering but in many other fields of contemporary society. The physicist today has been drawn out of his shell into the stream of life. He can well heed the words of the poet Schiller, "Talent develops in solitude, character in the stream of life." The physicist in the new world must be a man of high character, mindful of the consequences of his discoveries; deliberately seeking for the present those things that will help win the war, and for the future those that will contribute to a better world.

Tyndall Cone Apparatus

A SIMPLE and permanent apparatus for showing the scattering of light when it passes through matter in the colloidal state—commonly called the Tyndall cone effect—is a convenience for the demonstrator. The source of light is a 6.3-v radio pilot lamp, operated from a small transformer. A small achromatic lens, such as is used in cheap motion-picture projectors, is mounted vertically above the lamp so as to form a convergent beam of light. The light passes through the bottom of a beaker or cylinder containing the material to be studied. The distances from lamp to lens and from lens to beaker should be adjusted until the best effect is produced. Once these optimum distances have been determined, a wooden box can be built to make the apparatus permanent. The transformer and lamp are mounted on the bottom of the box, the lens is supported above it in any convenient manner and a piece of window glass is mounted in the top of the box to support the beaker. One side of the box should be made removable, to facilitate adjustment or repair.

A suitable material is starch, prepared by adding a few drops of a thin starch paste to about 100 ml of water and stirring. Water or starch can then be added until the sharpest cone is obtained. A very few small drops of India ink to 100 ml of water will also serve well, as will a small pinch of colloidal gamboge.—H. J. ABRAHAMS AND H. J. DUBNER, *J. Chem. Ed.* **20**, 61–62 (1943).—J. D. E.

The Status of Courses in Physics and of Physics Departments in Institutions of Higher Education—October, 1942*

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IN October, 1942, the American Institute of Physics sent a questionary to the physics departments of approximately 700 institutions of higher education seeking information about staff effectiveness, number of degree candidates, and enrolment in undergraduate and graduate courses of instruction. The present report is based on the returns from this questionary and on data made available to the Institute by the National Roster of Scientific and Specialized Personnel, taken from its questionary circulated in the spring of 1942.

The Roster survey covered all institutions of higher education listed in the *Educational Directory* of the U. S. Office of Education. From 1547 forms sent out, 1065 replies were received. It is believed that this represents very nearly complete coverage of those institutions in which physics is taught. The Institute sent its questionary to all institutions, omitting junior colleges and normal schools, from which the Roster received a reply, and to a number of institutions that did not reply to the Roster inquiry but might be expected to make an appreciable contribution to the study. Replies were received from 385 colleges and universities (71.5 percent return), 21 professional and technological schools (63.5 percent return) and 69 teachers' colleges (55.5 percent return). Institutions were classified and data tabulated by (*a*) type of institution, (*b*) geographic region and (*c*) "size," as determined by the enrolment in the general, introductory college physics course. Certain data were also obtained separately for women's colleges.

INSTITUTIONAL COVERAGE OF INSTITUTE SURVEY

Table I shows the distribution of returns by geographic region and by type and class of institution. Geographic regions are based on the sections covered by various accrediting agencies, this being the plan followed by the Roster in its

* Prepared for the American Institute of Physics.

TABLE I. Distribution of institutions submitting data for the October, 1942 survey.

Type of institution	Region	Class I	Class II	Class III	Class IV	Total	Returns of forms (percent)
Colleges and universities	1	6	10	3	12	**31**	77.5
	2	29	13	8	24	**74**	74
	3	45	14	6	29	**94**	69.5
	4	74	41	10	34	**159**	72
	5	9	5	3	10	**27**	64
TOTAL		163	83	30	109	**385**	71.5
Professional and technological schools	1	0	0	0	0	**0**	0
	2	1	0	1	6	**8**	67
	3	0	0	0	3	**3**	75
	4	1	0	2	5	**8**	73
	5	0	1	0	1	**2**	100
TOTAL		2	1	3	15	**21**	63.5
Teachers' colleges	1	0	0	0	0	**0**	0
	2	12	1	0	0	**13**	81
	3	7	3	2	2	**14**	56
	4	21	10	1	2	**34**	52
	5	5	0	0	3	**8**	73
TOTAL		45	14	3	7	**69**	55.5
TOTAL		**210**	**98**	**36**	**131**	**475**	68.5
Return of forms (percent)		65.5	76.5	75	83.5	68.5	

TABLE II. Ph.D. candidates reported to the Institute.

Type of institution	1942–1943 Men	Wmn.	Total	1943–1944 Men	Wmn.	Total	No. of institutions
Colleges and universities							
Region 1	10	0	10	8	2	10	5
2	31	0	31	33	2	35	14
3	13	2	15	7	0	7	6
4	27	3	30	39	2	41	16
5	6	0	6	5	0	5	3
Total	87	5	92	92	6	98	44
Professional and technological schools	5	0	5	4	0	4	3
Teachers' colleges	—	—	—	—	—	—	0
TOTAL	92	5	97	96	6	102	47

survey. Regions are defined as follows:

Region 1—New England (New England Association of Colleges and Secondary Schools): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont.

Region 2—Middle Atlantic States (Middle States Association of Colleges and Secondary Schools): Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania.

Region 3—South Atlantic and Southern States (Southern Association of Colleges and Secondary Schools): Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Virginia.

Region 4—North Central States (North Central Association of Colleges and Secondary Schools): Arizona, Arkansas, Colorado, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, New Mexico, North Dakota, Ohio, Oklahoma, South Dakota, West Virginia, Wisconsin, Wyoming.

Region 5—Pacific Coast States (Northwest Association of Secondary and Higher Schools): California, Idaho, Montana, Nevada, Oregon, Utah, Washington.

The "size" classification used is based on the enrolment (1941–42) in the general college physics course with laboratory rather than on the total institution enrolment for two principal reasons: (1) the procedure involved is much simpler, data being already at hand, and (2) enrolment in elementary physics was believed to be a better criterion for classification, since the study was concerned solely with physics departments and not with entire institutions, which include schools of commerce, education, law, and so forth. Although there is probably a reasonably close correlation between physics enrolment and institution enrolment, no claim is made that the classification is actually based on institution size. Use was therefore made of the following grouping into four classes according to 1941–42 *enrolment in general college physics with laboratory:*

Class	*Enrolment*
I	0– 39
II	40– 79
III	80–119
IV	120 and over

The grouping by type of institution follows that of the *Educational Directory* (1941–42). Negro institutions are included in the appropriate type groups.

It will be seen from Table I that: (*a*) the proportion of returns is reasonably uniform for various sections of the country; (*b*) returns from the "larger," class IV, institutions are proportionately larger than from other classes; and (*c*) the proportion of returns is considerably smaller from teachers' colleges than from other groups. One is justified in concluding that while the returns are not entirely complete, they represent an adequately distributed sampling.

CANDIDATES FOR Ph.D. DEGREES

Department heads were asked to "give the best possible estimate of the number of graduate and undergraduate majors in physics who will complete their courses during the periods indicated," October, 1942 to July, 1943 and July, 1943 to July, 1944, "provided that their courses are not interrupted."

It will be seen from Table II that 47 institutions reported Ph.D. candidates as follows: expected to finish between October, 1942 and July, 1943, *97*; expected to finish between July, 1943 and July, 1944, *102*. Six institutions known to

TABLE III. Number of Ph.D. degrees granted and number of candidates expected to complete degrees during various years at a limited number of institutions for which complete data are available. Data prior to 1942–43 taken from Roster survey.

Type of institution	Degrees					Degree Candidates						No. of institutions
						1942–1943			1943–1944			
	37–38	38–39	39–40	40–41	41–42	Men	Wmn.	Total	Men	Wmn.	Total	
Colleges and universities												
Region 1	14	15	17	19	13	10	0	10	8	0	8	4
2	20	19	18	14	17	21	0	21	20	4	24	9
3	10	6	5	6	6	8	2	10	2	0	2	4
4	37	38	43	46	45	25	2	27	28	0	28	15
5	3	5	3	5	6	6	0	6	5	0	5	3
Total	84	83	86	90	87	70	4	74	63	4	67	35
Professional and technological schools	2	1	1	2	2	1	0	1	2	0	2	1
Teachers' colleges	—	—	—	—	—	—	—	—	—	—	—	0
TOTAL	86	84	87	92	89	71	4	75	65	4	69	36

TABLE IV. Total number of Ph.D. degrees granted.

Source of data	29–30	30–31	31–32	32–33	33–34	34–35	35–36	36–37	37–38	38–39	39–40	40–41	41–42
Reference 1–2	89	94	113	123	121	150	147	158	148	165	148		
Roster survey									127	127	133	128	130

offer the doctoral degree in physics did not report; hence these data are not complete.

It will be borne in mind that the figures obtained are based on the assumption, specifically stated in the questionary, that the course of study of the candidate would not be interrupted. Since this assumption is almost certainly not in accordance with the probable course of wartime events, it would appear that the data presented do not actually represent the number of Ph.D.'s which *will* be granted, but are more nearly the maximum possible number of degrees which *could* be granted in 1943 and 1944 by the reporting institutions.

A continuous record of degrees granted and of degree-expectancy for the period 1937–38 through 1943–44 can be obtained for a limited number of institutions which replied fully to both the Roster and the Institute questionaries. Data from 36 such institutions are given in Table III and in Fig. 1. A longer time range can be obtained by "splicing" these data, with a suitable correction, on to those presented by Birge[1] and Henry.[2] The results are listed in Table IV and are shown graphically in the upper curve of Fig. 1. In spite of the uncertainties inherent in the 1942–43 and 1943–44 figures, there can be no doubt that fewer Ph.D. degrees will be granted in 1943 and 1944 than were granted in immediately preceding years.

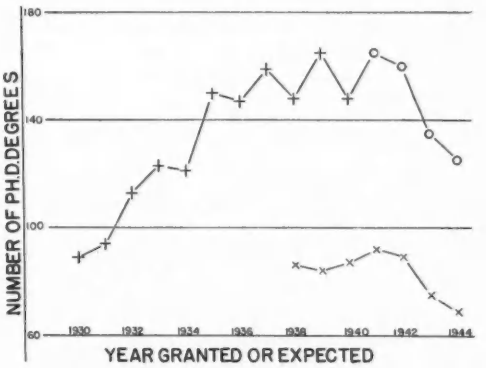

FIG. 1. Ph.D. degrees in physics granted (1930–1942) and degree candidates (1943 and 1944): + data from references 1 and 2; ○ data from Institute and Roster surveys "corrected" to fit data from references 1 and 2, using 3-yr (1938–1940) overlap period as basis for "correction"; × Institute and Roster data for 36 institutions.

[1] R. T. Birge, "On the training and prospects of the Ph.D. in physics," Am. J. Phys. **9**, 24 (1941).

[2] E. A. Henry, ed., *Doctoral dissertations accepted by American universities* (No. 1, 1933–34 *et seq.*; H. W. Wilson Co.).

TABLE V. Master's degree candidates reported to the Institute.

Type of institution	1942–1943 Men	Wmn.	Total	1943–1944 Men	Wmn.	Total	No. of institutions
Colleges and universities							
Region 1	18	2	20	19	3	22	12
2	47	5	52	48	4	52	20
3	23	1	24	35	2	37	14
4	87	3	90	61	1	62	29
5	6	1	7	7	0	7	8
Total	181	12	193	170	10	180	83
Professional and technological schools	8	1	9	6	0	6	4
Teachers' colleges	—	—	—	—	—	—	0
TOTAL	189	13	202	176	10	186	87

TABLE VI. Number of Master's degrees granted and number of candidates expected to complete degrees during various years at a limited number of institutions for which complete data are available. Data prior to 1942–43 from Roster survey.

Type of institution	37–38	38–39	39–40	40–41	41–42	1942–1943 Men	Wmn.	Total	1943–1944 Men	Wmn.	Total	No. of institutions
Colleges and universities												
Region 1	13	26	25	18	17	18	1	19	18	3	21	10
2	35	24	37	32	36	34	3	37	46	4	50	15
3	14	16	23	19	17	14	1	15	26	2	28	10
4	86	94	75	77	73	72	2	74	61	1	62	26
5	10	8	7	6	7	5	1	6	4	0	4	7
Total	158	168	167	152	150	143	8	151	155	10	165	68
Professional and technological schools	3	5	4	4	5	3	1	4	3	0	3	2
Teachers' colleges	—	—	—	—	—	—	—	—	—	—	—	0
TOTAL	161	173	171	156	155	146	9	155	158	10	168	70

CANDIDATES FOR MASTER'S DEGREES

As will be seen from Table V, 87 institutions reported candidates for the Master's degree as follows: expected to finish between October, 1942 and July, 1943, *202*; expected to finish between July, 1943 and July, 1944, *186*. The same uncertainties as to the accuracy and validity of these estimates apply as to those concerning Ph.D. candidates except that the likelihood of finishing a Master's degree on schedule is probably greater than for the Ph.D.

The 87 institutions reporting do not constitute all that offer Master's degrees in physics. A comparison of figures for a limited group of institutions for which a complete sequence of data is available with the grand totals from the Roster survey would indicate that the data given in Table V represent about 85 percent of the figures which would have been obtained in a coverage as complete as that of the Roster survey. This places the probable total number of Master's degree candidates for 1942–43 at 238 and for 1943–44 at 220.

TABLE VII. Total number of masters' degrees awarded, 1937–38 to 1941–42. Data from Roster survey.

37–38	38–39	39–40	40–41	41–42
240	231	239	221	216

No data have been found on Master's degrees awarded prior to 1937–38, so a long-range comparison such as was made for the Ph.D. degree is impossible. Table VI shows Master's degrees awarded and degree candidates for a limited number of institutions for which a complete sequence of figures were available from the Roster and Institute surveys. These data, together with Roster totals (Table VII) and "projected" Institute data are shown graphically in Fig. 2.

CANDIDATES FOR BACHELOR'S DEGREES

Of 500 institutions, 319, or 64 percent, listed physics major candidates. On the assumption

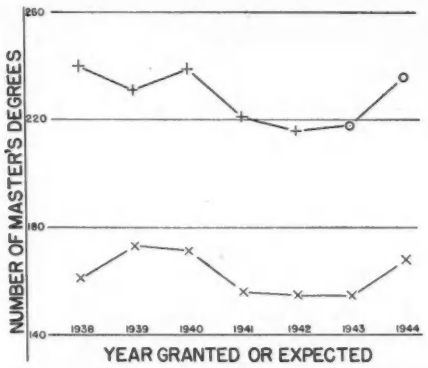

FIG. 2. Master's degrees in physics granted (1938–1942) and degree candidates (1943 and 1944): + data from Roster survey; O data from Institute and Roster surveys "corrected" to coverage of Roster survey; × Institute and Roster data for a limited number of institutions.

that their courses will not be interrupted, the number of undergraduate physics majors expected to complete the Bachelor's degree between October, 1942 and July, 1943 is 1360, while the number expected to complete this degree between July, 1943 and July, 1944 is 1806 (Table VIII).

A comparison of figures for a limited number of institutions (Table IX) for which a complete sequence of data was available with the total Roster figures for the same years (Table X), indicates that the aforementioned totals represent about 93 percent of the figures which presumably would have been obtained if the Institute survey coverage had been as complete as that of the Roster. Use of this correction factor gives the following figures "corrected" to the coverage of the Roster survey: October, 1942 to July, 1943, *1460*; July, 1943 to July, 1944, *1940*.

Complete data on majors for the entire period 1937–38 to 1943–44 are available for a limited number of institutions and are reported in Table IX and Fig. 3. From these data percentage

TABLE VIII. Physics majors expected to receive the Bachelor's degree as reported to the Institute.

Class, type and region	1942–1943 Men	1942–1943 Wmn.	1942–1943 Total	1943–1944 Men	1943–1944 Wmn.	1943–1944 Total	No. of institutions with definite data	No. of institutions listing majors	Institutions listing majors (percent)
Class I									
Colleges and universities	175	25	200	240	25	265	210	86	41
Prof. and tech. schools	17	0	17	2	0	2	( )	(2)	
Teachers' colleges	44	7	51	59	11	70	45	14	31
Total	236	32	268	301	36	337	255	100(102)	39
Class II									
Colleges and universities	310	16	326	333	23	356	77	66	86
Prof. and tech. schools	—	—	—	—	—	—	—	—	—
Teachers' colleges	32	0	32	57	7	64	15	10	67
Total	342	16	358	390	30	420	92	76	82.5
Class III									
Colleges and universities	98	10	108	138	20	158	35	32	91.5
Prof. and tech. schools	2	0	2	2	0	2		(1)	
Teachers' colleges	2	0	2	2	0	2	1	1	
Total	102	10	112	142	20	162	36	33(34)	92
Class IV									
Colleges and universities	527	28	555	764	29	793	110	104	94.5
Prof. and tech. schools	37	0	37	63	0	63		(5)	
Teachers' colleges	27	3	30	27	4	31	7	6	86
Total	591	31	622	854	33	887	117	110(115)	94
Totals									
Colleges and universities	1110	79	1189	1475	97	1572	432	288	66.5
Prof. and tech. schools	56	0	56	67	0	67	—	(8)	
Teachers' colleges	105	10	115	145	22	167	68	31	45
Total	1271	89	1360	1687	119	1806	500	319(327)	64
Region 1	125	13	138	211	19	230	31	25	81
2	312	34	346	413	40	453	82	58	71
3	175	6	181	235	18	253	108	65	60
4	388	18	406	481	17	498	181	116	64
5	110	8	118	135	3	138	30	24	80
Women's colleges		36			45		57	12	21

TABLE IX. Number of undergraduate physics majors graduated and expected to graduate in a limited number of institutions for which complete data are available.

Class, type and region	1937–38	38–39	39–40	40–41	41–42	42–43	43–44	No. of institutions	No. of institutions listing majors	Institutions listing majors (percent)
Class I	136	148	162	151	127	174	221	222	84	38
II	198	184	184	215	211	263	331	77	63	82
III	75	69	68	84	84	101	121	32	27	84
IV	267	265	323	309	358	446	664	95	89	94
Total	676	666	737	759	780	984	1337	42o	263	62
Colleges and universities										
Region 1	73	75	78	96	87	136	226	29	23	79
2	131	99	139	147	174	227	285	66	43	65
3	79	92	93	95	93	118	170	91	51	56
4	263	261	274	268	299	316	405	165	101	61
5	43	45	50	45	34	75	83	24	18	75
Total	589	572	634	651	687	872	1169	375	236	63
Professional and technological schools	10	13	13	16	11	13	31		(4)	
Teachers' colleges	77	81	90	92	82	99	137	51	27	53
Women's colleges	20	25	21	27	23	34	43	—	—	—

TABLE X. Total Bachelor's degrees in physics, 1937–38 to 1941–42.

1937–38	38–39	39–40	40–41	41–42
969	977	1073	1129	1163

increases may be calculated using the average number of majors in the two-year period 1937–39 as a base. This information is shown in Table XI and in Fig. 4. It is evident that the number of physics majors graduated each year was gradually increasing in the period prior to 1942 and that this gain would continue, probably at an increased rate, if the present college juniors and seniors were allowed to continue their courses.

Other interesting information may be obtained from these data. The number of majors per institution may be found and, drawing on the enrolment figures for the general physics course,

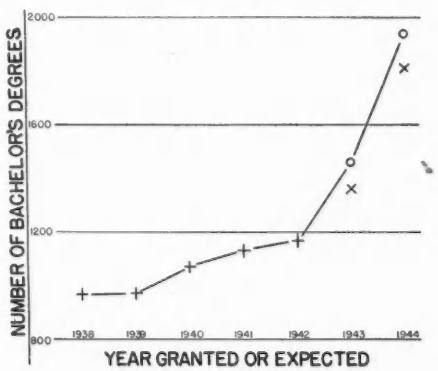

FIG. 3. Bachelor's degrees in physics granted (1938–1942) and degree candidates (1943 and 1944): + data from Roster survey; O data from Institute and Roster surveys "corrected" to coverage of Roster survey; × Institute survey totals.

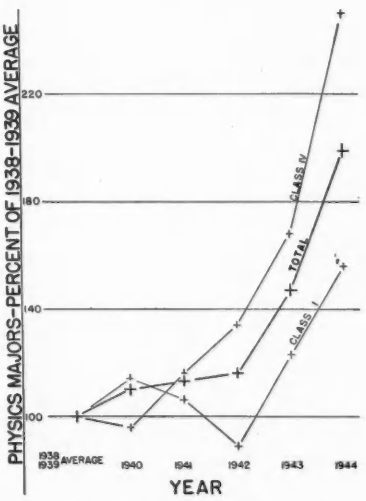

FIG. 4. Percentage change from 1938–1939 average in number of Bachelor's degrees in physics granted or expected. Data from Class I (small) and Class IV (large) institutions represent extremes.

TABLE XI. Percentage increase in the number of Bachelor's degrees granted in physics and in degree candidates over the average number in 1937–38 and 1938–39. Data are from a limited number of institutions only.

Class, type and region	Av. No. 37–38 38–39	39–40	40–41	41–42	42–43	43–44
Class I	142	+14	+ 6	−11	+23	+ 56
II	191	− 4	+13	+10	+38	+ 73
III	72	− 5	+17	+17	+40	+ 68
IV	266	+21	+16	+34	+68	+150
Total	671	+10	+13	+16	+47	+ 99
Colleges and universities						
Region 1	74	+ 5	+30	+17	+84	+220
2	115	+21	+28	+51	+97	+148
3	86	+ 8	+10	+ 8	+37	+ 98
4	262	+ 5	+ 2	+14	+21	+ 55
5	44	+14	0	−23	+70	+ 89
Total	580	+ 9	+12	+18	+50	+102
Teachers' colleges	79	+14	+17	+ 4	+25	+ 73
Women's colleges	22.5	− 7	+20	+ 2	+51	+ 91

the average ratio of enrolment in the general course to the number of majors graduated per year can be computed. The results are shown in Tables XII and XIII. Apparently in the smaller institutions a greater proportion of students taking the elementary course go on in physics than in larger institutions.

The figures in the last column of Table IX are the percentages of institutions reporting which list some majors during the period 1937–38 to 1943–44 and are at least approximately indicative of the proportion of institutions offering undergraduate physics majors. As might be expected the proportion is greater for large institutions (94 percent) than for small (38 percent). It is higher for colleges and universities generally than for teachers' colleges and lower for institutions in the South than elsewhere.

TABLE XII. Physics majors per institution listing majors—1941–42.

Class	I	II	III	IV	Average
	1.5	3.35	3.1	4.0	2.96
Region	1	2	3	4	5	Average
	3.8	4.0	1.8	3.0	1.9	2.96

TABLE XIII. Average number of students enroled in the general college physics course for each major graduated—1941–42.

Class	I	II	III	IV	Average
	20	22	37	94	49
Region	1	2	3	4	5	Average
	49	47	72	44	153	49

COURSE ENROLMENTS

The Institute questionary asked for enrolments in courses coming under 11 topic-headings as follows:

(1) General college physics, without laboratory.
(2) General college physics, with laboratory.
(3) Mechanics.
(4) Heat.
(5) Sound (acoustics).
(6) Light (optics).
(7) Electricity and magnetism.
(8) Electronics and ionics.
(9) Radio and radio circuit theory.
(10) Molecular, atomic and nuclear physics.
(11) All others.

Courses under topics (3) through (10) were specified as "beyond general physics." It was requested that, where course titles did not coincide with topic headings, enrolments be listed under the heading most nearly descriptive of the material covered. This arrangement very nearly parallels that in the Roster questionary except that "Electronics and ionics" has been added and "Molecular, atomic and nuclear physics" replaces "Modern physics." Because of these changes, comparisons between Roster and Institute figures for these fields, and possibly for radio, may not be as reliable as those for other fields.

CHANGES IN ENROLMENT

By comparing Institute data for the fall session of the academic year 1942–43 with Roster data for 1941–42, changes in total enrolment may be noted. Since the lists of institutions rep-

resented in the Institute and in the Roster returns differ slightly, the summation of enrolment for comparison purposes was necessarily limited to fewer institutions than listed enrolment in any particular course in either survey. The practice in many institutions of offering certain advanced courses in alternate years also limits the number of institutions for which comparable data are available. Because of these limitations, percentage changes only are shown in Table XIV and Fig. 5 together with the number of institutions for which data were available from both Roster and Institute surveys.

According to a preliminary report based on returns from a questionary sent out by the U. S. Office of Education, the total enrolment in institutions of higher education was approximately 14 percent less in October, 1942 than in October, 1941. The enrolment of men students decreased 15.5 percent; of women, 11 percent; that in junior colleges dropped 24 percent; in teachers' colleges and normal schools, 21 percent; in liberal arts colleges and professional schools, 11 percent. These changes in over-all enrolment form a background against which to set the reported changes of enrolment in physics courses. Because of the predominance of men students in physics, the 15.5-percent decrease in male students may be more nearly related to the physics data than is the 14-percent figure for all students.

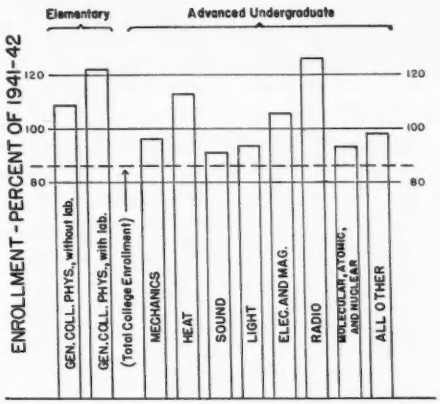

FIG. 5. Percentage change in enrolment in certain undergraduate physics courses, fall 1942 compared with 1941–42 figures. Change in total college enrolment over the same period is also shown.

While it is believed that the data on enrolment

TABLE XIV. Percentage changes in enrolment in undergraduate physics courses—1942 (fall term) compared with 1941–42. The numbers in parentheses give, for each case, the number of institutions for which comparable data were available. Figures in square brackets are for cases in which the number of institutions considered is less than half of the total number reporting some enrolment in the course.

Course	Average	Class I	II	III	IV	Colleges and universities	Prof. and tech. schls.	Teachers' colleges	Colleges and universities				
									Region 1	2	3	4	5
General physics													
Without lab.	(59) +8.5	(15) −11	[(10) +33]	(5) +39	(29) +3	(47) +9	(4) +7	(8) 0	(6) +9	(9) −6	(7) −2	(14) +21	(11) +10
With lab.	(407) +22	(181) +48	(86) +38	(29) +26	(111) +17	(331) +25	(13) −1	(63) −25	(28) +44	(66) +22	(76) +14	(137) +23	(24) +45
Advanced undergraduate													
Mechanics	(94) −4.1	(18) −21	(23) −15	(7) −5	(46) −1	(90) −3	(3) −12	[(1) −2]	(10) −10	(26) +2	(17) −2	(29) −7	(8) +21
Heat	[(55) +13]	[(4) +67]	[(15) +14]	(6) −17	(30) +15	(47) +12	(4) +26	(4) −19	[(3) −10]	[(9) +32]	(13) +24	(21) +14	[(1) −20]
Sound	[(19) −9]	(0) —	(4) +7.5	(4) −7	[(11) −11]	(15) −10	(2) −12	(2) +10	(3) −33	[(2) −15]	(5) −12	[(3) +2]	(2) +5
Light	(57) −6.5	[(6) +22]	(11) +2	[(3) +20]	(37) −10	(54) −12.5	(3) +29	(0) —	(8) +25	(14) −2	(10) +8	[(18) −3]	(4) −54
Electricity and magnetism	(142) +5.5	(26) −11	(30) +6	(13) +15	(73) +6	(129) +4	(6) +28	(7) −38	(17) −3	(26) +17	(21) −46	(52) +24	(13) +25
Radio	(76) +26	[(14) −37]	(27) +48	(8) +84	(27) +9	(66) +33	(4) +31	(6) −40	(8) +11	(15) +18	[(9) +54]	(28) +41	(6) +19
Molecular, atomic, and nuclear physics	(79) −7	[(11) +49]	(22) +1	(7) −12	(39) −7	(73) −9	(2) +29	(4) −18	(6) +62	(22) +25	(12) −47	(25) −6	(8) −47
All others	(70) −2.2	(21) +2	[(12) +4]	(9) +55	[(28) −35]	(64) −26	[(1) +150]	(5) −31	[(8) −71]	(20) −10	(12) −18	(21) −22	[(3) −65]
Total enrolment in all advanced undergraduate courses	−1.7	−6	+11	+28	−7	−3.2	+27	—	−8	+7	−4.5	−3	−29

TABLE XV. Enrolment in undergraduate physics courses, 1941–42, based on 1065 replies received in inquiries sent to 1547 institutions by the Roster.

Course	Total enrolment
General college physics	
Without laboratory	16,873
With laboratory	78,460
Advanced undergraduate	
Mechanics	3,638
Heat	2,656
Acoustics	1,650
Optics	3,070
Electricity and magnetism	5,107
Radio	3,647
Modern physics	2,971

changes are, on the whole, reasonably reliable, certain factors which limit their accuracy should be mentioned:

(i) The restriction of data, for the aforementioned reason, to a limited number of institutions lessens the accuracy since there is no proof that these institutions are typical of all in a particular class or region. Figures in square brackets in Table XIV are the ones least reliable on this account, the number of institutions involved in these cases being less than 50 percent of the total number reporting some enrolment in the course concerned.

(ii) The Roster questionary asked for enrolment during the academic year 1941–42 whereas the Institute data are only for the beginning of the fall term of 1942–43. This will lead to discrepancies (*a*) where a course was repeated both semesters of 1941–42 and the total enrolment for both semesters was reported, and (*b*) where the 1941–42 figures are for the second half of a full year course, such figures being almost certainly lower than for the first semester of the course.

Whether a particular percentage change is significant or not depends on how large a "random" yearly fluctuation in enrolment may be expected under "normal" conditions. This obviously is a function of the number of institutions involved, tending to be smaller for a large group of institutions than for a small group. This consideration will certainly limit the significance of the change in any one course, class or region. With this limitation in mind, the following summary would seem to represent adequately the significant changes in enrolment:

(1) Enrolment in general college physics both with and without laboratory work has increased, the latter considerably more than the former.

(2) In the case of general college physics with laboratory, the variation of increase with region and with class of institution is of interest. The increase in enrolment is largest in the smaller institutions. It is larger in the New England and Pacific Coast areas than elsewhere and is smallest in southern colleges.

(3) The total enrolment in all advanced undergraduate courses has decreased slightly but not as much as has the total college enrolment during the same period.

(4) Enrolments in heat, in electricity and magnetism and in radio have increased by significant amounts, the increase being most notable in radio.

(5) Wide variations in enrolment changes occur among different geographic regions and classes of institutions some of which are undoubtedly real (note, for example, the regional distribution of changes in enrolment in electricity and magnetism) and for which there is no obvious explanation.

(6) Various courses show decreases in total enrolment but, in general, these are less than the reported drop in college enrolment. It would thus seem that enrolment in physics courses has gained perceptibly with respect to college population.

(7) No data were available on changes in enrolment in graduate courses, since the Roster survey did not request this information.

TOTAL ENROLMENT IN UNDERGRADUATE COURSES

Table XV shows the enrolment during the year 1941–42 in undergraduate courses in the 1065 colleges, universities, professional and technological schools, teachers' colleges, junior colleges and normal schools supplying information to the Roster.

In Table XVI the Institute survey of total enrolment as of October, 1942 in undergraduate courses in the 476 colleges, universities, professional and technological schools, and teachers' colleges is broken down by region and by class and type of institution. The number of institutions offering each course is also given. *These data, because of the different coverage, are not to be compared directly with those of Table XV.*

Table XVII shows the percentage of reporting institutions offering each course in the fall semester of the 1942–43 academic year. Table XVIII

TABLE XVI. Total enrolment in undergraduate physics courses and the number of institutions offering each (figures in parentheses) as of October, 1942 in 476 institutions. The data are *not* directly comparable with those of Table XV.

Course	Total	Class				Colleges and universities	Prof. and tech. schls.	Teachers' colleges	Colleges and universities				
		I	II	III	IV				Region 1	2	3	4	5
General physics													
Without lab.	(104) 8016	(29) 754	(22) 713	(9) 1108	(44) 5411	(83) 6774	(7) 858	(14) 384	(8) 1356	(16) 1239	(16) 1281	(30) 1807	(13) 1091
With lab.	(465) 67400	(201) 5941	(95) 6919	(35) 4036	(134) 50504	(377) 59674	(21) 4611	(67) 3115	(29) 5374	(75) 14113	(91) 11754	(155) 20633	(27) 7800
Advanced undergraduate													
Mechanics	(155) 2603	(35) 302	(41) 372	(14) 244	(65) 1685	(142) 2086	(6) 404	(7) 113	(12) 225	(33) 865	(28) 301	(55) 555	(14) 140
Heat	(112) 1551	(19) 124	(33) 286	(11) 131	(49) 1010	(99) 1284	(6) 211	(7) 56	(8) 80	(25) 525	(18) 202	(40) 357	(8) 90
Sound	(41) 549	(4) 61	(8) 44	(5) 51	(24) 393	(33) 356	(4) 129	(4) 64	(4) 31	(7) 61	(9) 104	(9) 102	(4) 55
Light	(108) 1369	(26) 150	(22) 191	(7) 119	(53) 909	(97) 1091	(4) 217	(7) 61	(10) 145	(23) 325	(19) 213	(37) 336	(8) 72
Electricity and magnetism	(216) 3738	(49) 406	(51) 500	(21) 311	(95) 2521	(193) 3169	(10) 500	(13) 69	(21) 304	(37) 780	(37) 584	(82) 1202	(16) 239
Electronics and ionics	(68) 1049	(14) 138	(8) 59	(8) 181	(38) 671	(59) 864	(6) 162	(3) 23	(6) 112	(9) 168	(10) 114	(25) 37	(8) 99
Radio and radio circuit theory	(131) 2560	(31) 468	(43) 779	(12) 440	(45) 873	(112) 2031	(8) 342	(11) 187	(13) 176	(28) 474	(19) 348	(43) 896	(9) 137
[Radio+electronics]	[(199) 3609]	[(45) 606]	[(51) 838]	[(20) 621]	[(83) 1544]	[(171) 2895]	[(14) 504]	[(14) 210]	[(19) 288]	[(37) 642]	[(29) 462]	[(68) 1267]	[(17) 236]
Molecular, atomic and nuclear physics	(110) 1197	(27) 201	(28) 218	(10) 96	(45) 682	(103) 1097	(2) 58	(5) 42	(7) 105	(32) 413	(20) 123	(35) 327	(9) 129
All others	(148) 3066	(37) 404	(38) 659	(14) 176	(59) 1827	(137) 2764	(4) 191	(7) 111	(17) 127	(34) 1007	(23) 454	(49) 872	(14) 304
Total enrolment in all advanced undergraduate courses	17682	2254	3108	1749	10571								

shows the average enrolment per institution in various courses.

Estimates of total current enrolment in the institutional group represented in the Roster survey might be made by applying the change in enrolment data given above to the Roster totals for last year. Such a procedure would involve the assumption that changes in enrolment are the same for institutions not included in the Institute survey as for those included for which comparative figures were available. Since it is felt that this assumption is not justified because of the different nature of the two groups, no attempt at "correction" has been made.

Table XIX shows the ratio of students per institution in the general course to students in

TABLE XVII. Percentage of reporting institutions in which some enrolment in various undergraduate courses is listed.

Course	Average	Class				Colleges and universities	Prof. and tech. schls.	Teachers' colleges
		I	II	III	IV			
General physics								
Without laboratory	23	14	31	25	33	21.5	32	20
With laboratory	98	96	92	97	100	98	95	96
Advanced undergraduate								
Mechanics	33	17	40	39	49	37	27	10
Heat	24	9	32	31	37	26	27	10
Sound	8.5	2	8	14	18	8.5	18	6
Light	23	12	21	19	40	25	18	10
Electricity and magnetism	45	23	50	58	71	50	45	19
Electronics and ionics	14	7	8	22	28	15	27	4
Radio and radio circuit theory	27.5	15	42	33	34	29	36	16
Molecular, atomic and nuclear physics	23	13	27	28	33.5	27	9	7

TABLE XVIII. Average enrolment per institution in physics courses—October, 1942.

Course	All institutions	Class I	II	III	IV
General physics					
Without lab.	77	26	32	123	123
With lab.	145	29.5	73	115	377
Advanced undergraduate					
Mechanics	17	8.5	9	17.5	26
Heat	14	6.5	8.5	12	20.5
Sound	13.5	15	5.5	10	16.5
Light	12.5	6	8.5	17	17
Electricity and magnetism	17.5	8.5	10	15	27
Electronics and ionics	15.5	10	7.5	23	17.5
Radio and radio circuit theory	19.5	15	18	37	19.5
Molecular, atomic and nuclear physics	11	7.5	8	9.5	15
Weighted average of all advanced undergraduate courses	15.5	9	10.5	18	21

TABLE XIX. Average number of students (per institution) in general physics with laboratory per student in advanced undergraduate courses.

All institutions	Class I	II	III	IV
9.5	3.5	7	6.5	18

advanced undergraduate courses. Similarities between the data in this table and those in Table XIII will be noted.

TEACHING STAFF

In the Institute survey, department heads were asked to "give a thoughtful estimate of the teaching effectiveness of the physics staff, taking into account (1) the number of individual teachers, (2) the fraction of their time devoted to physics training and (3) the general ability of these individuals as teachers: (*a*) as a rough percentage of the corresponding status on May 1, 1942; (*b*) as a rough percentage of corresponding 'pre-war normal' status, for example, Fall 1939–40." The replies of each department were weighted by multiplying by the number of staff members listed for that institution in the Roster survey, and averages were found by regions and by "size" classes. Averages were made only for colleges and universities since the number of usable replies from the other types of institutions was too small to give a significant result. Results are shown in Tables XX and XXI.

TABLE XX. Percentage effectiveness of October, 1942 teaching staff compared with that of May, 1942.

Region	Class I	II	III	IV	Average
1	110	89	90	87.5	88
2	105	96	99	89.5	92
3	96	94.5	100	94.5	95
4	96.5	99	74	88.5	89.5
5	100	71	80	81	82.5
Average	99	94	86	90	90.5

TABLE XXI. Percentage effectiveness of October, 1942 teaching staff compared with that of "pre-war normal" times.

Region	Class I	II	III	IV	Average
1	116	83.5	90	75	78
2	98	88.5	78	78.5	81
3	96.5	92	100.5	79	84.5
4	97	100	65	71.5	76
5	94	59	65	69	71
Average	97	91	75	75	79

THE sense of uselessness is the severest shock which the human system can sustain.—THOMAS HENRY HUXLEY.

George Walter Stewart

Recipient of the 1942 Oersted Medal for Notable Contributions to the Teaching of Physics

The American Association of Physics Teachers has made the seventh of its annual awards for notable contributions to the teaching of physics to Professor George Walter Stewart, of the State University of Iowa. The addresses of recommendation and presentation were made by Professor A. G. Worthing and Professor A. A. Knowlton, on January 22, 1943, during the twelfth annual meeting of the Association.

George Walter Stewart, Nominee for the 1942 Oersted Award

A. G. WORTHING
University of Pittsburgh, Pittsburgh, Pennsylvania

GEORGE W. STEWART, in *A letter from father to son on youth and higher education*,[1] charges college and university teachers of physics with a grievous, albeit unintentional, failure. He says, "Our college graduates do not acquire an adequate amount of self-confidence in the possibility of their achievements, each one at his own level of attainment. Concomitantly, there is quite too much of defeatism, of flabbiness of character, and of the absence of the spirit of fight and of the willingness to strive against odds." For this failure on our part he presents ". . . at least three reasons why higher education does not contribute more to the self-confidence of the student." (i) At graduation "he has become saturated with respect for the great masters in all fields." (ii) "We educators . . . infer that only the very unusual or the extraordinary person does anything creative that is of any consequence." (iii) "We allow students to believe too definitely that great ideas, when they occur to man, come quickly into being, and that if one has only a wee, little but new idea in his own environment, he really hasn't anything worth cultivating." Founded on the experience of many years as a teacher, research worker and

[1] Sch. and Soc. **53**, 234 (1941).

department head, these words suggest a guiding principal—that of encouragement for the beginning creative efforts of students—which explains in no small way why we honor their author here today.

GEORGE WALTER STEWART was born in St. Louis, Missouri, February 22, 1876. He was granted a bachelor's degree by DePauw University in 1898 and a doctor of philosophy degree by Cornell University in 1901. Later he was awarded honorary degrees of doctor of science by DePauw and the University of Pittsburgh. He served as an assistant and an instructor in physics at Cornell from 1899 to 1903. From 1903 to 1909 he was in charge of physics at the University of North Dakota. In 1909 he was made professor of physics and head of the department at the University of Iowa, positions which he has held continuously since that time. He is a member of many scientific societies, including that most distinguished one, the National Academy of Sciences. Two of them—the Society of Sigma Xi and the American Physical Society—he has served in the capacity of president.

His publications fall into four rather distinct groups. Up to 1942, there were 33 journal articles, largely research, dealing with acoustics, 29 journal articles, also largely research, dealing with x-rays, 22 miscellaneous journal articles, most of which deal with the problems and ideals of the teacher of science, and two books, one jointly with PROFESSOR R. B. LINDSAY, both relating to acoustics. To the activities represented by the foregoing, we may add that he was connected with vital research problems in acoustics during the first World War, that he was acting dean of the graduate school of the University of Iowa for two years, that he campaigned and was largely responsible for the establishment of the School of Religion at his institution, that he established and has been a moving spirit in the highly successful conference of physics teachers known as the Iowa Colloquium of College Physicists, and that, as the most important of his activities by far, he has been the teacher to whom many younger physicists may refer with pride as their professor of physics.

PROFESSOR STEWART seems to have had a particular appeal for the mature students. Up to the present, 65 doctor's degrees have been awarded from the department. That this greater appeal to the advanced student is perhaps natural has been suggested by DEAN HOMER L. DODGE, the first man to work out a Ph.D. degree with STEWART. Speaking on the occasion of the presentation of a portrait of PROFESSOR STEWART to the University of Iowa in 1938, DEAN DODGE said:

> With students, as with himself, he was exacting. He lived and taught devotion to the job, the burying of oneself in the objective. Some students were restive under this rigid spiritual discipline, but all profited by it as students and in after years. I use the word "spiritual" advisedly, for I believe that we have all recognized that Professor Stewart was devoted to physics as if it were a god to be worshipped and to be served.

This same idea of devotion to physics on the part of PROFESSOR STEWART runs through the comments of other physicists who have been closely associated with him.

Another characteristic of STEWART is described by the single word "pride." According to LIEUTENANT H. R. LETNER, "he takes great pride in himself, his home and his physics department. He is a model of personal neatness, a fact to which his secretary often used to draw my attention." A similar comment is made by PRESIDENT SIEG of the University of Washington, the first of the 65 to gain doctorates at Iowa after Stewart's arrival and who continued for many years as a member of its physics staff:

> The first thing I remember about him was his insistence on good apparatus for lecture demonstrations, and, particularly, neat apparatus. I remember that in my lectures I used to assemble extemporary apparatus by the use of waste baskets, boxes, and all kinds of odds and ends. He, characteristically, substituted a series of neat black blocks of different sizes, which had the effect of increasing the students' regard for the substantial nature of physics.

Still another outstanding characteristic of PROFESSOR STEWART is his tendency to go to the bottom of things. MR. RUFUS FITZGERALD, a close associate in religious and fine arts activities at Iowa for several years, now Vice Chancellor of the University of Pittsburgh, tells of his "pumping" questions which were addressed not only to his associates at the University but also

on occasions to guests at dinner parties, sometimes to the embarrassment of the hostess. This process of pumping he apparently applied to himself as well. One associate has said, referring, it is true, to the construction of his very lovely home and the reasons for its various features, "I doubt if there was a single feature for which he had not rationalized a scientific reason." I recall such a pumping which I personally experienced several years since when at the Nela Research Laboratory. More than on the occasion of any other questioning by visitors during my 15 years' stay at that institution, I was forced to go down to the basic foundation of things.

In the plans for the library in his department at the University of Iowa, PROFESSOR STEWART left space for a large mural which should depict in a broad way the contribution of physics as an "aid to the happiness, peace and prosperity of the people." Eventually a mural entitled "Physics and Society," executed as planned by STEWART, was completed in 1939 and dedicated to the memory of DOCTOR E. O. DIETERICH, the first of Iowa's Ph.D.'s in physics to die. The mural pictures certain significant changes of attitude toward the forces of nature that have come about since the time of primitive man, and the present scientific approach so characteristic of physics. A climbing figure in contemplative attitude suggests "man's realization that his present situation represents less a conquest completed than a struggle well begun."[2] With this mural and its story of accomplishment and of promise for the future before him in his hours of study, what student of physics would not develop a pride in the accomplishments of his chosen field and resolve to further its aims?

These characteristics of leadership in the development of physics, personality, thoroughness and pride do not suffice by themselves to make a great teacher of physics. One must have for his procedures guiding principles that appeal to the earnest and thoughtful student. One such principle is suggested by the criticism in the aforementioned letter from a father to a son, already quoted: "We allow students to believe that if one has only a wee little but new idea in his own environment, he really hasn't anything worth cultivating." To the proposition which is implied—that students should have the opportunity to create and to develop their ideas—we all give hearty assent, but how many of us have preached and practiced accordingly? PROFESSOR STEWART asks the question, "Shall the class forsake this book of information, no matter how excellent it may be, and do a little individual and independent work?" and he answers, "It is not easy for a teacher to give a secondary place to knowledge . . . though he evidently should." Elsewhere[3] he has said, "More is demanded of the teacher than mere learning and good routine teaching ability. We must have men and women who are naturally aggressive, forward-looking, creative individuals. . . ." We have, I believe, thought too much of supplying interesting information and too little of our opportunities in assisting in the growth of the human mind.

The idea of encouraging the exercise of creative ability has been taken outside the classroom by PROFESSOR STEWART, to the summer Colloquium of College Physicists. To its meetings, physics teachers have been especially invited to bring their own new creations in the way of apparatus and teaching methods. How we have responded to this invitation is indicated by the enrolment for the 1941 session. The total was 117, with representatives from 84 institutions in 22 states —very significant testimony on the value of the appeal to creativeness as a guiding principle.

Mr. President, in presenting GEORGE WALTER STEWART as the 1942 candidate for the Oersted Medal, your committee on awards wishes to call particular attention to his insistence on thoroughness in the treatment of subject matter, to his searching ways, to his emphasis among students of the belief that physics has a highly important place in civilization, to his establishment of summer conferences for physics teachers, to his many discussions of the problems of physics teaching and, lastly, to his advocating and applying the guiding principle that the student of physics shall have opportunity to create in his chosen field. As a teacher and as a man he is worthy to be listed with those who have already been awarded Oersted medals.

[2] From a description by the artist, Richard F. Gates, Am. J. Phys. **7**, 319 (1939).

[3] Sch. and Soc. **38**, 341 (1933).

Presentation of Award by Professor A. A. Knowlton

The group of physicists is a small, and as I think, a very select company. The achievements and even the intimate personal characteristics of every man long in the service are well known to his fellows. I venture to suggest that this intimate acquaintance of one physicist with another makes the award of the Oersted Medal an occasion of particular significance. It is a time when in formal manner we may tell one of our fellows that we appreciate the good will, the good fellowship, the good work and the inspiring leadership for which we have long been accustomed to look to him. In so doing we make formal recognition of the honor and dignity and worth that he has added to our profession.

PROFESSOR STEWART, it is my great privilege as well as my personal pleasure to be the agent in transmitting to you the Oersted Medal of the American Association of Physics Teachers for 1942.

Teaching of Tomorrow

G. W. STEWART
State University of Iowa, Iowa City, Iowa

POSTWAR planning is now seriously active in various agencies of our government. Today our colleges and universities are busily adjusting their facilities to new Army and Navy requirements. Tomorrow postwar changes will become of paramount importance to educators. Whatever may be the readjustments finally made at this institution or at that, certainly the attitude of physics teachers can become a great leavening influence directing the long-range purpose of education and giving it a more appropriate spirit. We have a chance that should be emphasized.

At the conclusion of peace we as a people will become engaged in two struggles, one assisting in the gradual establishment of a better civilization in all countries of the world, and the other preventing, so far as possible, the economic storms that might otherwise occur in our own country. Neither physics nor the teaching of it can have a very direct influence in solving either of these problems of society. But I would assume it to be our duty to ascertain what service we are competent to render, be it great or small, and then to accept that obligation seriously. To this end, acting under space limitation, but one question will be put and answered. Wherein is our chance, as teachers of physics, to make contributions to the kind of civilization that we may envisage for our own country?

At once you will think of the possibilities of many applications of science, and of physics in particular, that result in a benefit to the entire people. Tempting as may be the vision of the stream of ingenious physicists coming out of our laboratories and ultimately doing much for the health, comfort and happiness of mankind, it is well to emphasize an opportunity for the teaching of physics that is less obvious but that deserves serious attention. I refer to certain attitudes of the teacher, which, while not lessening his zeal in the training of physicists, nevertheless have a broader significance. With seven million college graduates living in this country at the close of the war, and a larger proportion in the years to come, the possible influence of education in our future civilization challenges the imagination.

Of course education will be influential in developing leadership among our people, but if the attitude of teachers is right we can, without subtracting from our effort in this direction, do much for the education of all, even those who do not come within our classrooms.

What are we wishing for society in this country? I venture that a poll of the American Association of Physics Teachers would show the majority in favor of the following trends: less contrast between the extremes of riches and poverty, less geographical concentration of industry and of population, a wider diversity of the labors of the people, with a better balance between manufacturing and agriculture in the same community, less hunger, with starvation never facing anyone, less illiteracy, better housing, improved medical care, and numerous other changes in conditions that will occur to anyone. But do you realize that in this country today there are regions that conform closely to this pattern? Why is not more said of them? For the reason that they are not eminently satisfactory. A youth in Iowa, for example, may tell you, if he is thoughtful, that the evenness of life in that state does not fire his imagination. He finds it somewhat humdrum. Evidently in altering our civilization in the direction of a more regulated economy, of a limitation, through taxation, of the accumulation of wealth, of better care of the people, of greater security, we are introducing more and more obstacles to the cultivation of initiative, to the inspiration of our youth to become creative and to rise as far above the general level of attainment as native ability will permit. Of this the education of tomorrow must take cognizance in a positive manner. Physics has the chance to be particularly valuable in enabling youth to escape the bonds of mediocrity.

By the time one comes to college he has had twelve years of formal schooling. His reasoning power, his breadth of view and his knowledge have all been increased during this period. Shall we continue his education with the same emphasis? In the light of what has been said, should not the student more definitely have his dormant creativeness aroused?

The graduate departments of physics in our country have never taught that there is only one kind of creativeness in physics that is worth while, namely, the type of research that is required for the Ph.D. degree in science. On the contrary, those who conduct graduate training know that it is the existence of the creative activity of the teacher which is worth while, and not the form which it takes. My own professor of physics in a Liberal Arts college never engaged in a piece of research in his entire career, but he had the good judgment to encourage his own creativeness in the design and construction of new forms of apparatus. His students could not fail to observe that for him there was something living in the subject. This impressed us far more than any exhortation could possibly have done.

Now no one can fail to see that creativeness enters into every nook and corner of life and that each individual has a detectable measure of creative ability. If youth is to rise above the median level in an almost monotonous and uninspiring evenness of life, each individual must exhibit creativeness at his own level of attainment. And what is our part? Physics is rich in creative opportunity, far richer than nonscientific subjects in the curriculum. It is a field that is constantly growing, constantly changing in its concepts and applications. New devices, new methods and new improvements in the effectiveness of the laboratory are constantly needed. In the classroom not only can the teacher apply his ingenuity, but he can also lead the students to do so. We teachers must constantly remind ourselves that we are not to hold fast to tradition, that we should not allow ourselves to fit the groove which our time schedule, our finances and teaching hours seem to make for us. It is our struggle to get out of the bonds of mediocrity that will inspire our students to do likewise.

If in any community one will examine the life of a successful man, he will likely find that this successful individual has depended upon just this type of struggle, upon taking two and two and obtaining something besides four. What I am saying now is not intended to point the way to the achievement of the greater personal success which will inevitably ensue. It is to bring out clearly an obligation to the society of the future through our personal emphasis upon creativeness. We can do this through the student

by individual encouragement, and we can do it also by example.

Let none deny that the opportunity for creativeness exists in every teaching position, no matter how meager the equipment or how heavy the teaching schedule. Usually many inconsequential things occupy one's time. They should make way for efforts of greater importance. The determination to neglect the unimportant seems almost mysteriously to amplify the length of the day. A number of years ago, under the auspices of the National Research Council, I visited 60 colleges in the Middle West in the interest of the "gifted student." In each institution I naturally was taken to the physical laboratory and there found what the professor of physics had uppermost in his mind. I must acknowledge that I was surprised and almost shocked at the too general absence of a fighting creative spirit. In all but a relatively few colleges the professor had finally succumbed to the limitations of his environment. Doubtless today, because of the efforts of the Association of Physics Teachers, the conditions are much better. Let us hope that a consideration of the need of future society for the inspiration of a creative atmosphere will give new motivation to all teachers of physics, those in the one-man departments and those in our largest universities.

But a few further suggestions should be made to give a better picture of the attitude in physics teaching here emphasized. Space permits only two remarks. The attitude of the laboratory I have described would not be well-rounded unless the self-confidence of the student is increased through his own activity. He should be encouraged to do something with his physics. He should use it. The teacher can find the way, and in so doing he will arouse the interest and self-confidence of all the students, including the ablest as well as the mediocre. I have been told by more than one teacher of physics that though he desired to be more creative, yet he did not seem to think of new ideas. In this assumption he deceived himself. The truth is, new ideas literally jump into the mind of each one every day. They seem to have their origin partly in the fact that one day does differ from another. The detail of the environment and the course of one's thoughts change. If there are but very few ideas present at any moment, this can be explained only by the fact that each one of them has such a short life. They are habitually dismissed so rapidly that no impression of them remains. It is true that most of these ideas are practically worthless, but the habit of dismissal will dull the perception and lessen any possible effort in separating the sheep from the goats. The time required for an occasional embryonically good idea to grow into one that is recognized as certainly worth while will differ with the individual. It is important to remember constantly that ideas must be cultivated until they show whether they are good or not. This growth requires time even in the mind of a genius. Other folk can ill afford to dismiss ideas so readily. Admittedly the soil for growth differs with the individual, but it is to be insisted that good ideas can be cultivated in the mind of anyone. The teacher of physics must keep his self-confidence and give time for the active cultivation of helpful ideas.

I have often noticed that teachers can scarcely lay aside the robes of instruction even in social conversation. The present occasion has evidently induced me to retain the role of teacher and to attempt to make certain suggestions for the future. Whether or not I have in this brief space been convincing, at least the effort has been made to speak of activities and attitudes that can and should strongly influence the education of the future. I have spoken not of special skills which are only meagerly transferable. One may have confidence that the transfer of the habits and attitudes here mentioned can be made from physics to other problems of life. For example, a determined attitude toward creativeness at one's own level of attainment will lead to economic security in any walk of life. I need not further emphasize the importance of these three aspects of teaching—an atmosphere of creativeness, the development in the student of self-confidence, and alertness to cultivate ideas on the part of both teacher and student. Yes, I have been speaking of education of the future without mentioning any details of curriculums and courses. The spirit that must be emphasized should transcend in importance any details. There may be many ways of arranging details; the spirit is basic. Educators must encourage and

emphasize an adequate spirit in the education of tomorrow. This spirit cannot be the old one which was adequate for a pioneer day. It must be a changed one. I have attempted to show that this can be obtained by a new emphasis clearly seen, well understood and devotedly practiced. What has been urged will not appear visionary to one who believes in the efficacy of education. Physics teaching has a great opportunity in the education of the future, not so much in the numbers of students it can touch directly as in the quality of its service in leavening the entire process of education. I wish the American Association of Physics Teachers every success in its future efforts to make the teaching of physics even more useful to society.

Newton and the Law of Gravitation

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SINCE Christmas day, 1942, was the three-hundredth anniversary of the birth of Newton it may not be amiss to add another article to the interesting one published in the December issue of the Journal.[1] During Newton's boyhood and youth he seems to have given relatively little sign of the genius that was definitely in evidence by his twenty-third year. Owing to the plague much of the following two years, 1665 and 1666, was spent away from the University of Cambridge, in his country home in Lincolnshire. It is probably not an exaggeration to say that his mental achievements at this time surpassed those of any other scientist. However, these achievements were not known to the outside world until many years later because of that curious secretiveness characteristic of him. It was during these two years that he began his investigations on gravity, fluxions (calculus) and the composition of light.

So far as is known there is extant no manuscript of Newton's pertaining to gravitation that was written in this period. There are, however, several lines of evidence which make it highly probable that he was then considering the problem of gravitation. He wrote two letters in 1686 which allude to his early work on this subject,[2] and there is a statement written by him about 1714 that was found in 1887 by the astronomer J. C. Adams in the "Portsmouth Collection" of Newton's papers. Though it has been shown that this statement was written by Newton, as Ball says,[3] "the original is cancelled and hence it is not indisputable evidence; but it is believed that, except for certain dates, it is substantially correct." The portion[3] of the memorandum pertaining to gravity is as follows:

> And the same year [1665 or 1666] I began to think of gravity extending to y^{e} orb of the Moon, and having found out how to estimate the force with w^{ch} [a] globe revolving within a sphere presses the surface of the sphere, from Kepler's Rule of the periodical times of the Planets being in a sesquialterate proportion of their distances from the centers of their Orbs I deduced that the forces w^{ch} keep the Planets in their Orbs must [be] reciprocally as the squares of their distances from the centers about w^{ch} they revolve: and thereby compared the force requisite to keep the Moon in her Orb with the force of gravity at the surface of the

[1] Metzdorf, "Sir Isaac Newton," Am. J. Phys. **10**, 293 (1942). For those interested in the life of Newton, J. W. N. Sullivan's *Isaac Newton* (Macmillan, 1938) is recommended. L. W. Taylor's *Physics, the pioneer science* (Houghton, Mifflin) also contains much interesting material on the law of gravitation as well as on other important discoveries and should find a place in the library of all physics teachers.

[2] W. W. R. Ball, *An essay on Newton's Principia* (Macmillan, 1893), pp. 156, 162.

[3] Reference 2, p. 7.

> earth, and found them answer pretty nearly. All this was in the two plague years of 1665 and 1666, for in those days I was in the prime of my age for invention, and minded Mathematicks and Philosophy more than at any time since. What Mr. Hugens has published since about centrifugal forces I suppose he had before me.

As additional evidence, two colleagues, Pemberton and Whiston, refer in their writings early in the eighteenth century to Newton's work on gravity in 1666.

As Newton stated in the quotation, he deduced the inverse square law from Kepler's harmonic law—namely, that the square of the periods of the planets are proportional to the cubes of their mean distances from the sun—and from the expression for the acceleration of a body moving with constant speed in a circle. The derivation is simple if the assumption is made that the orbit of the planets is circular.

> Suppose a planet moving in a circular orbit of radius a has a period P. Then the speed v of the planet is $v = 2\pi a/P$, or $v \propto a/P$. From Kepler's harmonic law, $P^2 \propto a^3$. Hence $v^2 \propto 1/a$. But the force F necessary to hold the planet in its circular orbit is proportional to v^2/a. Therefore, $F \propto 1/a^2$; that is, the force necessary to hold the planets in their orbits (assumed circular) is inversely proportional to the square of their distances from the central sun or, as Newton expressed it, "reciprocally as the squares of their distances from the centers about w^{ch} they revolve."

Newton's investigations on the subject of gravity were suggested, according to a well-known anecdote, by his contemplation of the fall of an apple while sitting in his country garden. Ball, in his essay on Newton, states that the story rests on good authority. Catherine Barton, Newton's favorite niece, who married Conduitt the assistant to Newton at the Mint, told the story to Voltaire. Conduitt, who had exceptional means of information because of his position, also vouches for the story. Pemberton and Folkes, the latter Vice President of the Royal Society during the last few years of Newton's tenure as President, both tell the same story. Thus it would appear that Newton told the "apple" story to several of his intimate friends in the latter part of his life, and there is little reason to doubt its authenticity.

The law of gravitation was not widely known until after the publication of the *Principia* in 1686. A few years prior to this many scientists were meditating on what fundamental physical laws underlay the empirical laws of Kepler. Some of the ablest minds in the Royal Society apparently had concluded that the elliptical orbits of the planets were due to an attractive force from the sun which varied inversely as the square of the distance. Halley describes a meeting in January, 1684:

> I met with Sir Christopher Wren and Mr. Hooke, and falling in discourse about it, Mr. Hooke affirmed, that upon that principle all the laws of the celestial motions were to be demonstrated, and that he himself had done it. I declared the ill success of my own attempts; and Sir Christopher, to encourage the enquiry, said, that he would give Mr. Hooke, or me, two months time, to bring him a convincing demonstration thereof; and besides the honour, he of us, that did it, should have from him a present of a book of 40 shillings. Mr. Hooke then said, that he had it, but he would conceal it for some time, that others trying and failing might know how to value it, when he should make it public. However, I remember, that Sir Christopher was little satisfied that he could do it; and though Mr. Hooke then promised to show it to him, I do not find, that in that particular he has been so good as his word.

By August of that year no solution was forthcoming, so Halley went to Cambridge to see Newton and asked him what curve the planets, assuming an inverse square law of gravity, would describe. Newton is reported to have immediately answered, "an ellipse"; whereupon Halley asked how he knew it. Newton replied that he had proved it some years earlier. It turned out that he could not find his earlier calculations so he went to work again on the problem and sent the results to Halley sometime in November 1684. Thus Newton's interest in gravitation was reawakened, and by October he had worked out enough material for the course of lectures which he gave as Lucasian professor during the Michaelmas term. The duties associated with this professorship were one lecture a week during one term of the year and two conferences a week with students during the time in residence. Actually it appears his duties were even lighter for frequently no students turned up for lectures or conferences! The material contained in the nine lectures given during the Michaelmas term took the form of a tract entitled *De Motu*. When Halley saw it he was very much impressed

PHILOSOPHIÆ NATURALIS PRINCIPIA MATHEMATICA.

Autore *J S. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheſeos Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtat apud plures Bibliopolas. *Anno* MDCLXXXVII.

TITLE PAGE OF THE FIRST EDITION OF THE PRINCIPIA.

and reported it to the Royal Society. Halley's enthusiasm served as a catalyst in starting Newton on a piece of intensive work. In 17 months between December 1684 and May 1686 the *Principia* was written and sent to the Royal Society. During this time Newton's mathematical genius appears to have been the controlling interest of his life. Yet we are told that during this time he continued his chemical experiments. During Newton's life three editions of the *Principia* were brought out. The first was dated 1686, the second edition came out in 1713, the third in 1726 with Cotes and Pemberton, respectively, collaborating on the latter two. These editions were in Latin. The first English translation by Motte with notes appeared in 1729, and an excellent modern with numerous notes by Cajori appeared in 1934.[4]

As stated earlier, Newton said about 1714 that he first tested the law of gravitation in 1665 or 1666. In this report he says he "thereby compared the force requisite to keep the Moon in her Orb with the force of gravity at the Surface of the earth and found them answer pretty nearly." Why then did Newton delay nearly 20 years before announcing the law of gravitation? It has been commonly accepted, chiefly on the basis of a statement by Pemberton, that the delay was due to Newton's using in 1666 an incorrect value for the radius of the earth. Pemberton says Newton

> . . . took the common estimate in use among geographers and seamen, before Norwood had measured the earth, that 60 English miles were contained in one degree of latitude on the surface of the earth. But as this is a very faulty supposition, each degree containing about 69½ of our miles, his computation did not answer expectation; whence he concluded, that some other cause must at least join with the action of the power of gravity on the moon. On this account he laid aside for that time any farther thoughts upon this matter.

At the two hundredth anniversary of the publication of the *Principia*, in 1887, the astronomer J. C. Adams and the mathematician J. W. Glaisher challenged this commonly accepted explanation for the delay. They stated that it was not due to the use of an incorrect value for the radius of the earth but to Newton's appreciation of a more fundamental and difficult problem, namely, how a large spherical mass attracts an outside particle. This problem was not cleared up by Newton until about 1685, and not until then did he consider his proof of the law of gravitation as applied to the earth and moon to be valid. Cajori has investigated this matter very carefully, and anyone interested in it should refer to his excellent article.[5] Cajori shows that had Newton taken the value of 60 mi of 5000 ft each to a degree rather than 69½ mi of 5280 ft each, then, instead of the experimental value of 32.2 ft/sec² for the acceleration due to gravity, he would have obtained about 26.48 ft/sec², an error of over 18 percent! This would hardly have prompted Newton to say that he "found them answer pretty nearly."

A quotation from an article written by the astronomer H. H. Turner in the *London Times* of March 1927 may provide an interesting summary. He says:

> In fact Newton was stimulated by Halley's visit of 1684 to return to the whole question of gravity which had been intermittently in his thoughts since he saw the apple fall in the autumn of 1666. At that time the general idea of an attraction varying as the inverse square of the distance occurred to him, but he saw grave difficulties in its complete application of which lesser minds were unconscious. The most important of these he did not overcome until 1685, 19 years after the falling of the apple. It was that of linking up the attraction of the earth on a body so far away as the moon with its attraction on the apple close to its surface. In the former case the various particles composing the earth (to which individually Newton hoped to extend his law, thus making it universal) are at distances from the moon not greatly different either in magnitude or direction; but their distances from an apple differ conspicuously in both size and direction. How are the separate attractions in the latter case to be added together or combined into a single resultant? and in what "center of gravity," if any, may they be concentrated? The beautiful theorem which he discovered, showing that the total attraction of a sphere on an apple at its surface, just as on a distant satellite,

[4] F. Cajori, *Sir Isaac Newton's mathematical principles* (Univ. of California Press, 1934).

[5] F. Cajori, "Newton's twenty years' delay in announcing the law of gravitation," in *Sir Isaac Newton, 1727–1927* (Williams & Wilkins, 1928), p. 127; or see reference 4, p. 663.

is accurately concentrated at the center of the sphere, came as a complete surprise to him and must have given him great joy. It put the law of gravity on an entirely new footing, converting what had been possibly only a crude approximation for planetary bodies into an accurate and universal law. The discovery of it was a great achievement, representing an important step in integral calculus, and it is probable that the final success in solving it was only the sequel to many failures.

Two Graphical Constructions in Geometric Optics*

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AND

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THERE is nowadays less reluctance than formerly to present to undergraduate students topics in thick lens optics, perhaps a result of wide distribution of cameras. In any event it is to the advantage of the student to have the more useful method of handling his lens problems. In this connection we have used for solving a compound system a graphical solution which may be old, but by each of us has been considered original until occasion brought us together.

Numerous proofs are available for a general formula for the focal lengths of a compound system, yet a satisfactory graphical solution is uncommon. Let us then proceed as follows.

Given two coaxial systems, S_1 and S_2, with their cardinal points disposed for example as in Fig. 1. First draw a ray B_1B_2 parallel to the axis at a convenient distance h_1 from it. The conjugate ray in the image space of S_1 must leave the second principal plane at a height h_1, and it must pass through F_1'. Hence we can draw $B_3F_1'B_4$.

Now draw a ray A_4A_5 through F_2 parallel to the one just drawn through F_1'. Since these are parallel in the image space of S_1, they must pass through the same point in the focal plane in the object space. Hence we can draw $A_3A_2FA_1$.

Next consider B_3B_4 and A_4A_5 as being in the object space of S_2. A_4A_5 passes through F_2; therefore, its conjugate will leave A_6 parallel to the axis. So A_6A_7 is definite. Then the conjugate of B_3B_4 must pass through that point of A_6A_7 which is in the second focal plane of S_2, namely, B_6. This gives B_5B_6, by which F' and B_7 are located.

The ray B_1B_2 was arbitrarily selected, therefore F' is the second focal point of the system. As truly, F is the first focal point. Awkwardly enough for the student who happens to be measuring the focal length of this system, but conveniently indicated in this assumed arrangement of lenses, A_1 at the same distance from the axis as is A_6A_7, must lie in the first principal plane; also B_7 will locate the position of the second principal plane. The conventional proofs for focal length of the combination can be given directly from Fig. 1 if desired.

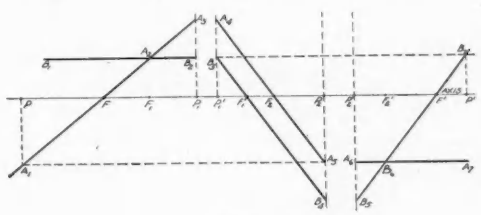

FIG. 1.

This simple construction is very helpful, though the student must be on the watch if he

* Publication assisted by the Ernest Kempton Adams Fund for Physical Research of Columbia University.

uses any negative lenses. Perhaps its usefulness is increased by applying it to the case of single lenses, since many teachers now like to present the relation,

$$\frac{n_1}{a_1}+\frac{n_2}{a_2}=\frac{n_2-n_1}{r},$$

as the fundamental one for all elementary problems. However, the construction fails in the case

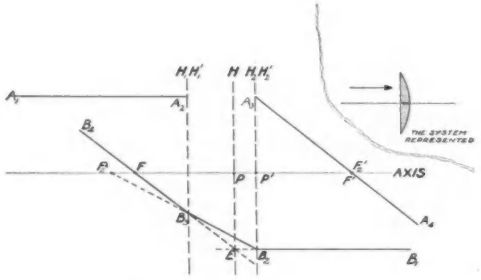

FIG. 2.

of the plano-lens considered as a combination of two systems.

After various compromises we now feel that the following solution, for which we are indebted to Mr. M. J. K. Newman, is the adequate answer to the case involving the plane surface of a lens in air.

The two systems, plane surface and spherical surface, may be represented by their principal planes H_1H_1' and H_2H_2', with the plane surface on the left where the light enters. (See Fig. 2.) Draw any ray A_1A_2 parallel to the principal axis and meeting the coinciding principal planes at A_2. Since this is a plane surface, the ray will proceed unchanged in direction to the point A_3 on the coinciding principal planes of the second, spherical surface. Clearly the conjugate ray will now pass through A_3 and through F_2', the second focal point of the second surface. This immediately identifies F_2' as being also F', and shows that H_2' is also H'.

Now draw a ray B_1B_2 in the image space of the combination parallel to the principal axis and at the same distance from it as is A_1A_2. The conjugate ray in the object space of the second component is B_2F_2, reaching H_1H_1' in B_3. Draw B_3B_4 parallel to A_3F'; this locates F on the principal axis and, by backward projection, gives the point E, thus locating the first principal plane of the combination.

There are numerous proofs that this is correct, but in view of the circumstances always involved in publication, we are inclined to quote a phrase already well known: "The proof will be left to the reader."

IF you do not expect the unexpected, you will not attain truth, which is difficult to discern, scarcely accessible.—HERACLITUS.

VON HELMHOLTZ was speaking of his own great teacher, Johannes Müller, and after referring to the student's need for "daily mental intercourse with teachers from whom he learns something of the workings of the thoughts of independent minds," he goes on to say, "Anyone who has once come in contact with one or more men of the first rank must have had his whole mental standard altered for the rest of his life."—H. R. ROBINSON, *Nature* **150**, 593 (1942).

Common Misconceptions Among First Year Students in College Physics

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AFTER many years of teaching physics, one begins to distinguish between his pupils' blunders and their misconceptions. Blunders are limitless. When the teacher thinks he has encountered every possible blunder in a given field, a new one is sure to crop up on the next examination paper he reads. But misconceptions fortunately are not nearly so numerous, because they imply thought, even if it is misdirected. They originate in outworn notions whose vitality is perennial, in lack of clarity or in positive misstatements in textbooks and in previous faulty instruction.

It is my purpose to give a course of five or six lectures at Trinity College for the benefit of teachers of physics in the schools of Hartford and neighboring towns. In these lectures I plan to discuss each of the 45 misconceptions listed below, with possible additions which may be sent to me as a result of this paper. Also, suggestions as to effective means of impressing the correct concept on a class will be offered, so that the misconceptions may be anticipated and destroyed before they take root. Readers of this journal need no discussion of most of the items on my list; hence, with a few exceptions they are given here only by title.

The impression is common among beginners:

(1) That they already know a lot of physics.

(2) That the *knot* in navigation is a distance.

(3) That a rocket needs air to push against.

(4) That in "point-blank range" the trajectory of a bullet is a straight line.

(5) That the *watt* is an *electric* unit of power.

(6) That *head* in hydraulics, like pressure, measures force per unit area instead of difference of gravitational potential.

(7) That mechanical advantage measures the efficiency of a machine.

(8) That Archimedes' principle tells us that a *submerged* body displaces its own weight of fluid.

(9) That water is the only substance that expands while freezing.

(10) That specific heat is the same as thermal capacity.

(11) That if no heat were lost, a steam engine would be 100-percent efficient.

(12) That the rate of evaporation depends upon atmospheric pressure.

(13) That the inverse square laws are special instead of general.

I find that not every physicist realizes that these laws are a property of three-dimensional space, and that they apply wherever anything extends in all directions from a point or sphere. In "flat land" there is an inverse first-power law. In a land of four dimensions an inverse cube law would hold.

(14) That the ideas of nodes and loops apply to traveling waves.

(15) That difficulty in hearing a sound when a breeze blows from the observer toward the source is due to "blowing the sound away" instead of tilting the wave front upward.

(16) That a musical interval is a *difference* of frequencies.

(17) That in Römer's method for finding the velocity of light, the interval between the observed eclipses is longest when the earth is farthest from Jupiter.

(18) That the sun and moon on the horizon are enlarged because of refraction by the atmosphere.

(19) That a plane mirror forms a perverted but not an inverted image of an object.

From one point of view a plane mirror neither perverts nor inverts. You hold a letter before a mirror and the reflected writing is reversed, but it was *you* who turned it around in presenting it to the mirror. If you had turned it over top for bottom as is done in examining a medal, the writing would appear upside down and not reversed. So again *you* are to blame and not the mirror.

(20) That there is no internal reflection when light emerges from a denser into a rarer medium, until the reflection becomes total.

(21) That when two prisms are combined to rectify a beam of light, the second prism recombines the colors separated by the first.

This fallacy I have already explained at length[1] so I will not discuss it further, but it dies hard!

(22) That a reading glass brings objects nearer.

(23) That a telescope *magnifies* the "fixed" stars.

(24) That the diffraction grating *bends* a beam of light like a prism.

(25) That in mixing pigments we *add* colors.

(26) That a mirage evolves an oasis and waving palms out of nothing.

(27) That a magnet *lifts* objects held by it.

(28) That the inverse square law applies to magnets instead of to individual poles.

Between two bar magnets, for example, the total force is the vector sum of four inverse square forces, two being attractions and two repulsions.

(29) That a magnet is "charged" with magnetism.

(30) That iron conducts magnetism.

(31) That lightning rods are intended to conduct lightning to the earth, rather than to prevent the stroke.

(32) That a wire carrying a current is *attracted* by a magnetic pole.

(33) That an electric motor operates by the attraction and repulsion of poles in the armature.

It is strange how this notion persists long after such a machine has disappeared except as a toy developing about one mousepower. In the Centennial Exhibition in Philadelphia a rather large motor of this type was exhibited, and a writer of that dark era wrote that the machine developed a very high speed, but could be stopped by putting the hand on the pulley; therefore it seemed unlikely that electric motors would ever have much practical value. Even the writers of some recent textbooks apparently fail to realize that the motor of commerce does not involve either attractions or repulsions, but the sidewise drag on the armature inductors. It is true that poles are set up in the armature, but they are practically stationary. In modern motors designed for greatly varying loads, field interpoles are used to neutralize the polarity of the armature, which is a nuisance in any case and especially so when the armature current and its magnetic reaction are subject to strong variations.

(34) That some heating units are more efficient than others in converting electric energy into thermal energy rather than that all have an efficiency of 100 percent.

(35) That emf is analogous to pressure.

(36) That "volts go through a man who is electrocuted."

This concept is particularly rife in newspaper science.

(37) That turning on an electric light in a house *increases* the resistance of the house circuit.

Most beginners have an unshakable belief that turning on more lamps increases the resistance, and that the load is larger because the emf has a harder time pushing current through the circuit. Apparently they think only in terms of series circuits. Also an open circuit to them means both zero resistance and zero current, so Ohm's law becomes $E/0=0$!

(38) That the light of an incandescent lamp is intrinsically different from that of an oil lamp, because it is electrical.

(39) That in the electrolysis of water, the acid serves only to make the water conduct.

(40) That an electric current is always directed from positive to negative in any portion of a circuit.

(41) That a storage cell stores up electricity.

(42) That stationary magnetic fields induce currents in stationary coils.

(43) That the field of a shunt generator uses up line current, instead of merely increasing the armature current.

(44) That weakening the motor field reduces the motor speed.

(45) That electrons constituting the current in a wire move with the speed of light.

Any additions to the foregoing list of misconceptions will be most welcome, as well as suggestions regarding the best way to counteract those that I have named.

[1] H. A. Perkins, Am. J. Phys. **9**, 188 (1941).

THAT by-products of science have created an unbelievably complex tangle of human ordering beyond our present means of guidance can scarcely be denied; but as a pattern of intelligence it still furnishes us the hope of deeper understanding and insight, and perhaps of some ultimate solutions.—RAYMOND B. FOSDICK

The Schools in a Physicist's War*

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AND

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HIGH school science teachers and administrators appear to have three principal responsibilities in relation to the manpower problem. The first is to provide a variety of courses suited to the abilities and previous training of various groups of high school students and geared to the needs of the war machine. The second is to select and guide boys into the courses in which they can make their best contribution to the nation's manpower. The third is to recruit, select and train girls for the work which they can do most effectively.

The willingness of high school personnel to meet these responsibilities is attested by the changes which have already been made in response to requests of Army, Navy and government officials for more and better training in science and mathematics. Recent studies made in the state of Indiana and in the Chicago area show that science and mathematics enrolments were substantially larger in the fall of 1942 than they were a year earlier. Physics enrolments increased slightly and, in addition, aeronautics courses have been introduced in a number of schools, with an enrolment about one-third as large as the physics enrolment. Plane geometry shows an increase of 16 percent in Indiana, with no significant change in the Chicago area. Advanced algebra shows a 13 percent increase in Indiana and a 10 percent gain in the Chicago area. Trigonometry shows a 25 percent gain in the Chicago area and 90 percent increase in Indiana.

These changes came in response to very general statements made last spring and summer about the nation's need for men with mathematical and scientific training. Now that manpower needs have been stated more clearly and more specifically, the high schools will really be put to the test.

Some of the major needs for the work of young people are the following:

Both the armed forces and industry immediately need personnel with a practical technical training, and they must be assured of a continual supply. The Army is expected to increase from 5,000,000 to 7,500,000 by the end of 1943. The Navy and the Coast Guard will also expand by several hundred thousand men. Practically all boys of ages 18 and 19 who can pass the physical examination will be inducted into the armed forces very soon. The Army is especially short of technically skilled automobile mechanics, airplane mechanics, radio operators, radio repairmen, electricians, telephone and telegraph linemen and repairmen, and machinists. Normally the Army takes men without any special training and sends them to an Army specialists school to learn one of the Army jobs in a period varying from three months to a year. But with the contemplated expansion from 5,000,000 to 7,500,000 men within a year, the Army's training facilities will be overtaxed. In this situation, General Somervell, Chief of the Services of Supply, has requested the civilian training agencies of the country to give as much preinduction training of a practical technical type as possible. Through its Preinduction Training Section the Army has specified the kinds of training that it needs.

The same shortage exists among scientifically trained workers. Men and women with a thorough scientific and technical education are in constant demand for service and research on behalf of the armed forces and in industry; and in order to keep available a continuous supply of such people, young men and women must be trained more rapidly and in greater numbers than ever before.

High school science and mathematics are needed by the young people who will help to meet current manpower needs. Preinduction training of a practical technical sort is needed by the great majority of boys who will be enlisted in the armed forces. Similar training is needed by girls who will go into industry as well as by boys who enter industry after failing to pass the Army physical examination. Scientific education of a more thorough kind is needed by those who prepare to fill the needs of military, industrial and civilian activities for a continuous supply of scientifically trained workers.

New courses in biology and chemistry are not needed, but differentiation of courses in physics

* From a report, "High school science and mathematics in relation to the manpower problem," issued by the Cooperative Committee on Science Teaching. The full report deals with the relation of the manpower problem to all the sciences and can be obtained from the Chairman, R. J. Havighurst, University of Chicago.

and mathematics seems to be indicated. The aim should be, in these fields, to provide appropriate courses for students who will work at jobs requiring varying levels of theoretical knowledge and practical skill. The manpower problem, as already indicated, is not only a problem of giving large numbers of boys a preinduction training of a practical technical sort but also of giving smaller numbers of boys and girls a thorough scientific training leading to scientific work in college so that they may meet the continuing need for scientifically trained workers.

At the present time the number of students enrolled in the physics classes of the secondary schools and the colleges does not meet the demands of the emergency. The technical developments during the last 50 years have been accompanied by a steady decline in the amount of physics taught in the secondary schools. The senior high school enrolment increased between 1890 and 1934 from 6 to 54 percent of the age group 15 to 17 years, inclusive. During the same period the enrolment in physics dropped from 19 to 6.3 percent of the total high school enrolment.[1]

In normal times the lack of technical training of the high school graduate has been supplemented by the vocational and trade schools directed by the large industries in their own plants. For the small percentage going to college a scientific education has been provided on a somewhat higher level. However, the total number of men and women trained in physics was and is a small fraction of our population. It is clear that the shortage of men trained in physics which exists on all levels cannot be effectively dealt with by the colleges, since the total output of physics majors in the colleges in normal years is less than 1000 per year. Thus we are confronted with the necessity of using the manpower reservoir in our secondary schools as the only source of the 50 percent or more of Army personnel who must have some training in the physical sciences and related mathematics.

The first problem facing us is the determination of the probable number of students in the secondary schools with an aptitude for physical science and mathematics. Physics and chemistry are usually taken in the eleventh and twelfth grades. The number of students enrolled in physics is about 25 percent of the twelfth grade enrolment. It is doubtful whether this enrolment can be more than doubled and still deliver personnel that can in the end acquire a mastery of even elementary skills in the physical sciences.

We, therefore, recommend that the high school population be screened according to their aptitude for work in physical science and mathematics. The Preinduction Section of the War Department has designated five areas as particularly important for the preparation of the future soldier. These courses—in electricity, machines, radio, shopwork and automotive mechanics—are designed to prepare the student for a large variety of Army jobs. To provide the large numbers needed, the War Department recommends that every boy in the eleventh and twelfth grade should devote one or two class periods a day to work in preinduction courses. Since every boy in these grades is eligible to take this work, it cannot be too advanced or abstract but will have to stress practical applications.

The numbers available for the academic courses and for the various emergency physics courses should be determined by the composite record of the results of an intelligence test, a mathematics and physics aptitude test, and previous school records in mathematics, general science and biology. The science aptitude test should be given at the end of the tenth grade to provide proper selection for the academic and preinduction courses given in the last two years of high school.[2] The outcome of such screening tests will determine not only the available number of trainees but also the number of teachers who must be trained for the increased number of

[1] U. S. Office of Education, *Offerings and registrations in high school subjects*, 1933–34, Bull. No. 6, 1938.

[2] Several aptitude tests for science and mathematics are available. One of these tests, developed by the Pennsylvania State College in collaboration with the Department of Physics of the University of Iowa, has been used widely in the ESMWT program in the state of Pennsylvania. Another, developed at Purdue University by a committee of the Department of Physics and the Division of Educational Reference, has been used by some schools in Indiana. There is also a science aptitude test developed by the U. S. Office of Education and other tests such as those used by industry and the science clubs.

students. If the number of students enrolled in the various physics courses is appreciably increased, we will face a serious teacher shortage.

New teachers may not be needed in the smaller schools because the physics teachers now engaged partly in other activities may be assigned to such additional physics classes as are created. It will be necessary, however, to train new teachers for the larger schools, particularly if the preinduction courses in machines, automotive mechanics, fundamentals of electricity and fundamentals of radio are to be given simultaneously with the regular courses of the schools.

With the draft age lowered to 18 years and the deferment rules rigorously tightened, it will be necessary to train a large number of women to take the place of the men gone into the armed services. These women will serve as teachers and as technicians for the defense laboratories. The screening test given at the high school level will determine the number of girls who can take physics courses in the high school as preparation for laboratory technicians.

To determine which women can be trained as teachers a screening science aptitude test should be given to all women students in the colleges. It is realized that such a test will not effectively test the ability of the student as a teacher but only her ability to learn and comprehend physical science and mathematics.

We have, therefore, three problems to discuss: (1) the preparation of teachers; (2) the wartime curriculum; (3) the development of teaching equipment for the new courses.

THE PREPARATION OF TEACHERS

The total high school enrolment in physics throughout the country is about 280,000. There are about 630,000 boys in the senior year, and 730,000 boys in the junior year. If all boys take college-preparatory physics or preinduction electricity and machine courses, the physics enrolment must increase by a minimum of about 400,000. An exact estimate can hardly be made, because a part of the physics enrolment consists of girls, and there are many small schools that do not offer physics and may not offer preinduction physics courses. But the figure 400,000 is conservative. If eleventh and twelfth grade boys flock into these courses at the same time, the increase will be even greater. And the more advanced preinduction courses in radio and automotive mechanics will demand the time of many physics teachers.

There are in the country 1700 high schools with enrolments over 1000. Estimates of the number of new physics teachers needed in these schools run from 1000 to 3000. Where can the new teachers be obtained? A few of them may be recruited from the ranks of high school teachers of other subjects who have some background in physics. These teachers should be selected on the basis of their performance in a science and aptitude test. Through intensive courses taken during the spring and summer such teachers may be ready to teach preinduction courses by next fall.

The most promising source of new teachers would appear to be the women now in college and the men in college who are ineligible for military service because of physical defects. However, it is evident that their services will be quite generally in demand. College men who are majoring in physics or chemistry will hardly be available for high school teaching because they are so greatly in demand by industry and for war research. College women who are majoring in physical science may be attracted to teaching, although they, too, will be in demand by industry.

College students who are not majoring in physics or chemistry but who have some background in physical science might be given intensive training for preinduction courses by teacher-training institutions. It is especially a responsibility of the state universities and of the larger independent universities to recruit and train people for these jobs. But the teachers colleges and liberal arts colleges can also do a great deal to meet the need. These institutions as well as state departments of education may have to make temporary adjustments for majors and for teachers' certificates. Emergency action is needed.

For the training of these special teachers, programs should be established in institutions of higher learning that still have a staff and facilities for this purpose. The question of sub-

sidy of these teachers while in training and while teaching any emergency course is of utmost importance. Since the prospective science teacher is also a prospective employee for war industries, it may be necessary to find means to subsidize his training period just as industries are subsidizing the training period of prospective employees.

In the ESMWT program the college instructor is compensated for teaching courses beyond his usual load. Extra pay for additional time spent in teaching or in the preparation of these intensive courses may also be necessary to keep high school science teachers on the job. Fundamentally, the problem of securing enough high school teachers of science and mathematics to meet emergency needs is the problem of paying them enough to attract them. The young people who might qualify for such positions can now get pay for learning a technical job in industry and can draw wages higher than teachers' salaries as soon as they learn their jobs.

The preparation of the teachers must differ from peacetime requirements. It is not possible to ask for a four- or five-year program. It will be necessary to develop a special program requiring from one to three quarters or semesters, depending on the background and training of the prospective teachers. Teacher-training courses in physics and mathematics may be organized in recognized training centers under the ESMWT program, a policy accepted during the last year by the U. S. Office of Education. The additional teachers fall into three groups:

(i) Teachers in high schools who are assigned to other subjects than physics but who hold a physics teacher's license. To reactivate this license we recommend a full-time program for one term in which the teachers will be trained in the content of the particular physics preinduction or emergency course which they are to teach.

(ii) Teachers of neighboring sciences who have some previous preparation in physics; We recommend the same program as that given in (i).

(iii) New teacher candidates with high scores in a science and mathematics aptitude test. They should be trained, depending on their background, in a two- or three-term full-time program in the fundamentals of mathematics, physics, electricity and radio. It may be necessay, if the emergency demands it, for teachers trained in such a manner to leave the university without obtaining a degree. They should be permitted to return after the war with full college credit for the work taken in preparation for emergency teaching.

THE WARTIME CURRICULUM

Recognizing the fact that many topics in the customary physics course have little or no relation to the war effort, we deem it essential to analyze the present physics courses from this point of view and to correlate them with the activities of the armed services. A procedure adopted in Indiana indicates a possible solution. A committee representing institutions of higher learning and the high schools has been appointed by the State Department of Education to analyze the topics to be given in secondary-school physics. The outline of an emergency physics course has been sent to all the schools in the state; it contains: (i) topics with reference by page and paragraph to each of the textbooks approved in Indiana; (ii) a list of lecture demonstrations to be carried out if necessary with simple home-made equipment; (iii) a description of simple student experiments; (iv) a summary of the fundamental relationships involved in the unit.[3]

In every unit reference is made to the technical and field manuals issued by the War Department as they are related to the material under discussion. The course stresses wartime applications throughout and eliminates other material usually covered in a first-year course. Thus, in optics, geometrical optics is stressed as applied to the optical devices used in the army. In sound, the chapters on musical acoustics have been eliminated, but propagation of sound, depth sounding, sound ranging, and so forth, are discussed in some detail. The course should also be integrated with shop courses so as to make more use in physics of machines and tools.

This course should be given in the eleventh grade so that it can be followed in the twelfth

[3] Copies of this outline may be obtained from Dr. C. T. Malan, State Superintendent of Public Instruction, Indianapolis, Ind.

by some of the advanced preinduction courses. Offering physics in the eleventh grade is also desirable because many colleges plan to admit students with 12 instead of the customary 16 high school units.

It is essential that a new physics program of this sort be brought to the attention of high school administrators and teachers early enough so that they can adequately discuss it and prepare for it. In Indiana a series of meetings was held in six counties with administrators and the teachers of science and mathematics. The whole program—screening test, teacher training and counseling, and the wartime physics and mathematics courses—was presented by representatives of the State Department of Education, members of the mathematics and physics emergency committee, and representatives of the colleges.

The preinduction courses in fundamentals of machines and electricity may well be taught as simple, practical courses for the great mass of boys, who will be assigned to learn technical jobs when they get into the Army. While the outlines of the preinduction courses issued by the War Department suggest a type of work which is not different from that in the college-preparatory physics course, it appears inevitable that the courses will be very much simplified for the large numbers of students who do not have special scientific ability or interest. In a large school with many classes of preinduction physics, this difficulty could be avoided by sectioning students according to ability. The sections of students with greater ability would then really be taking college-preparatory physics, except that the work would be concentrated in mechanics and electricity.

EQUIPMENT AND PRIORITIES

Just as the content of the physics course must be analyzed, so it is also necessary to determine the essential amount of equipment.[4] Through cooperation with the industrial art shops, which in many schools are excellently equipped for the ESMWT program, it will be possible to construct and build many of the pieces of equipment necessary for demonstration and student experiments. In electricity a great deal of equipment may be assembled from second-hand radio equipment, which can still be obtained. Wide use will have to be made of visual aids such as lantern slides or projection of illustrations from the Army technical manuals.

In some cases it will be necessary to establish priorities of a rating similar to that allowed for the ESMWT courses. In such cases a uniform procedure and general supervision should be established by the State Department of Education or some other state agency.[5] It is assumed that each high school will appoint a counselor to advise the school on the needs of the armed forces. This counselor will be indispensable in the purchase of equipment where priorities are involved.

* * *

The proper selection and guidance of students must follow the establishment of differentiated courses in physics and mathematics. The Army and the Navy have both adopted the policy of sending many young men to colleges with orders to follow college courses designed to prepare them for advanced technical work. Some of these men will be trained for specific military jobs. Others who will be trained as physicians, physicists, chemists and engineers may be sent into nonmilitary work if the war lasts long enough and civilian needs become urgent. While in high school, these young men should pursue the orthodox college-preparatory curriculum, with emphasis on science and mathematics.

It appears that at least 10 percent and probably a greater proportion of the boys of ages 18 and 19 will be selected for such postinduction college training. Thus, at least this proportion of boys should be advised to pursue the regular college-preparatory science courses. The War

[4] A special committee, appointed last spring by the Indiana State Department of Education, has set up certain minimum essentials necessary to keep the physics course a laboratory course. Physics teachers interested in this procedure should write to Professor E. S. Eliot, Butler University, Indianapolis, Ind., Chairman, Committee on Equipment and Supplies.

[5] A counseling service for the mathematics and science war programs in the schools has been established by the joint efforts of the Purdue University Engineering Extension Department and the Division of Education. A similar procedure in other states will be of great service to orient the teachers in their new job and to keep them informed as to new military and industrial developments and needs.

Department suggests that 20 percent of the boys in and out of school should follow "a war-applied course in physics and mathematics" as background for continued specialization at the college level. When we remember that only about 55 percent of the boys of age 17 are in school, we see that at least 20 percent and perhaps a larger proportion of high school senior boys should take college-preparatory science. The policy of giving all boys only preinduction courses of a practical technical nature would be a short-sighted one, for it would dry up the source of the continuing stream of scientifically trained personnel which is needed in war as well as in peace.

Women will become a more important part of the manpower reservoir as the war goes on. They will be more and more in demand as nurses, laboratory technicians, research workers, teachers and factory workers. Girls in high school should be guided into appropriate vocational channels on the basis of the same kind of information about their abilities as is used in guiding the boys. More girls should take biology and chemistry than have taken these courses in the past. The preinduction shopwork, electricity and machines courses should be open to girls who show some aptitude for work in these areas.

To obtain the greatest efficiency in the production of specialists and highly trained personnel a close correlation among preinduction courses in the high school, college-preparatory courses, preinduction and postinduction courses in college, training in the Army schools and the Army Institute will have to be provided. In no other fields is this as essential as in physics and engineering, where continuity of training and correlation of topics could eliminate unnecessary repetition and duplication and lead in the shortest possible time to advanced training.

The curriculum changes which are now taking place in the upper years of the high school should be regarded as temporary. These are emergency changes. No pattern for a permanent curriculum is likely to be found in them. Yet the experience of adapting science and mathematics teaching to the needs of immediate practical and fateful action should prove invaluable. Out of this experience, though not out of the emergency curriculum pattern, may come vital ideas for the improvement of postwar science and mathematics teaching.

Unscrewing Lens Mount

IN dismantling an eyepiece or photographic objective for cleaning, a lens mounting or knurled retaining ring is sometimes not readily unscrewed. Light oil may be effective if time is allowed for it to creep into the screw threads. But if force is necessary, it is best to avoid gripping the mounting in its original state. If the knurled edge protrudes, make two cuts with a hacksaw at opposite ends of a diameter; use an old hacksaw blade held in a vice as a key. If the ring is recessed, drill two holes; to make a key, cut an iron washer in half and file to shape.—D. A. CAMERON, *J. Sci. Inst.* **20**, 32 (1943).

NOTES AND DISCUSSION

Radio Side Bands Demonstration

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WHEN a continuous radio signal of frequency f is varied in amplitude at an audiofrequency n, the resultant amplitude modulated wave may be shown by a simple trigonometric substitution[1] to be equivalent to three continuous unmodulated waves. One of these waves has the frequency f of the original carrier; the other two are on each side of the carrier and separated from it by the audio-modulating frequency, their frequencies thus being $f-n$ and $f+n$. When a carrier is modulated by a number of audiofrequencies simultaneously, as in the case when the modulating signal is produced by voice or music, side bands are produced instead of merely two side frequencies.

Because of their important applications in radio theory it is desirable to be able to demonstrate the presence of side frequencies for instructional purposes. Morecroft[2] described a method of observing them using a very low value of f, thereby obtaining a sufficiently large percentage separation of the side frequencies from the carrier to permit their observation with a frequency meter. It does not seem to be generally known that these side frequencies can be observed at high radiofrequencies such as those within the broadcast band by the use of an ordinary signal generator, amplitude modulated at 400 cycle/sec, whose output is connected to the antenna terminal of a receiver having a beat oscillator for code reception. Any standard communication receiver is adequate, and no crystal filter for high selectivity in the receiver is necessary. If the receiver has a band-spread tuning dial, this may be calibrated and the exact separation of the side frequencies from the carrier measured in cycles per second.

In practice, additional side frequencies $f\pm2n$, and sometimes $f\pm3n$, can be heard. These could be produced by harmonic content in the audio-oscillator which modulates the radiofrequency signal, by some undesired frequency or phase modulation of the radiofrequency oscillator or by nonlinearity in the radiofrequency stages of the receiver. A parallel resonant circuit inserted in the lead from the audio-oscillator to the modulated radiofrequency oscillator had no effect, when tuned to $2n$, upon the intensity of the signals $f\pm2n$ in the receiver, showing that the latter were not produced by a second harmonic in the audio-oscillator output. As these frequencies $f\pm2n$ and $f\pm3n$ can be observed in the reception on 5 megacycle/sec of the tone-modulated government frequency standard station WWV, which would not be expected to contain any appreciable frequency or phase modulation, it is probable they are produced in the radiofrequency stages of the receiver.

[1] See any textbook on radio engineering.
[2] J. H. Morecroft, *Experimental radio engineering* (Wiley, 1931), p. 328.

Effect of Friction on Motion Down an Incline of Variable Slope

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ELEMENTARY textbooks commonly point out that, in the absence of friction, the kinetic energy and hence the speed acquired by a body descending a vertical distance h will be independent of the path followed. Extension of the discussion to cases in which the body experiences a retarding force μN, where N is the component of the weight of the body normal to the incline, yields an unexpectedly simple result. The fraction of the original potential energy diverted to overcoming friction is determined solely by the product of the coefficient of friction μ and the horizontal distance b traversed during descent. Therefore, the final kinetic energy and speed, for given coordinates of top and bottom positions, remain independent of the shape of the curve (provided there are no "stalling points"). Likelihood of this result was pointed out to the writer by a freshman student who at that time had not studied calculus.

The following derivation may, for pedagogic purposes, be set up in terms of a summation of finite quantities. (See Fig. 1.)

If x and y (positive y taken downward) represent the horizontal and vertical distances from the top of the incline, one may express the work done against friction as

$$\int_0^x \mu\left(mg\frac{dx}{ds}\right)ds=\mu mgx. \tag{1}$$

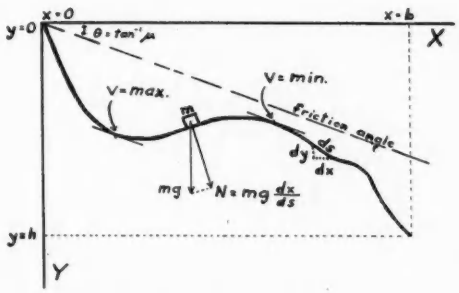

FIG. 1. Normal force on irregular incline.

The kinetic energy at the point (x, y) will be

$$\tfrac{1}{2}mv^2=mgy-\mu mgx, \tag{2}$$

and the corresponding speed,

$$v=[2g(y-\mu x)]^{\frac{1}{2}}. \tag{3}$$

A "stalling point," at which $v=0$, exists wherever $y=\mu x$; hence if the body is to reach the bottom of the incline, its path must remain below a line drawn at the friction angle $\theta=\tan^{-1}\mu$. The speed at any point is proportional to the square root of the distance below this line.

Although these results probably have appeared elsewhere, the writer is not aware of any reference to them.

Experiments with Polarized Light

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THREE simply constructed polarizing plates make possible a group of demonstrations capable of puzzling even those who are quite familiar with the phenomena involved. Designate the plates by *A*, *B* and *C*. If light traverses *A* and *B* in the order *A–B*, the plates appear to be ordinary Polaroid plates; a 90° rotation of one relative to the other changes the intensity of the transmitted light from maximum to zero. If, however, the order of passage is changed to *B–A*, maximum transmission occurs for all relative angular positions! Plates *A* and *C* likewise appear to be Polaroid plates for the order of passage *A–C*, but complete extinction results, at all relative angles, when the order of passage is *C–A*. Plates *B* and *C* give results identical to those obtained with *A* and *C*.

If a mica or Cellophane strip is placed between *A* and *B*, the explanation for these phenomena may be discovered. When the order is *A–B* it is quite evident that the light traversing the mica is plane polarized; in particular, the brightness of the color seen in the mica depends upon the orientation of the mica as well as upon the orientations of the two plates. When, however, the order is *B–A* the brightness of color is unchanged by orientation of the mica, thus proving that the light traversing the mica is *circularly* polarized.

Each of these polarizing plates is made by binding together a Polaroid plate and a quarter-wave plate so that the vibration axes of the latter make 45° angles with the plane of the vibrations passed by the Polaroid. As is well known, the light which then emerges from the quarter-wave plate will be circularly polarized; the direction of "rotation" is clockwise or counterclockwise, depending upon whether the "fast" vibration axis—direction of vibrations for the component that travels fastest in the quarter-wave plate—is turned 45° counterclockwise or clockwise from the plane of vibration of the light coming from the Polaroid. Plates *A* and *B* are alike; plate *C* differs only in the direction of rotation which it produces.

The demonstrations are explained as follows. When *A* and *B* are held so that the two Polaroids are adjacent, the light which passes from *A* to *B* is plane polarized and the results are indistinguishable from those observed with plain Polaroids. If, on the other hand, the quarter-wave plates are brought adjacent by interchanging *A* and *B*, the light passing between them is circularly polarized light produced by *B*. This circularly polarized light then is reconverted, by the quarter-wave plate in *A*, into plane polarized light whose plane always coincides with the transmission plane of Polaroid *A*. The same result could, of course, be brought about without changing the order of *A* and *B*, merely by turning each plate face for face. Similar explanations may be made for the other demonstrations.

Quite apart from the aforementioned demonstrations these polarizing plates are very convenient producers and analyzers for circularly polarized light. They are especially useful for demonstrations of photoelastic phenomena since, when circular polarization is employed, the double refraction pattern produced by loading the transparent models shows up equally well for all positions of the model and for all directions of strain.

More Misconceptions and Misinformation

ACQUIRING experience in teaching is at least partly a matter of learning the conceptual difficulties and misconceptions which the students are most likely to encounter, and of devising ways to correct or, better still, to circumvent them. Professor Perkins' list of misconceptions which appears elsewhere in this issue should therefore be particularly useful to physics teachers of relatively little experience or training—and the number of such teachers will certainly increase because of the wartime demand for something that approaches almost universal instruction in elementary physics.

Professor Perkins' manuscript proved so stimulating that we were moved to respond promptly to his request for additional items. Although our list consists mostly of stock items, familiar to experienced teachers, there is some point in making a start on a comprehensive list. Moreover, the mere act of verbalizing even a familar item adds to the chance that we will make better use of it.

A student is likely to enter the elementary physics course with the impression:

That it is not permissible to multiply or divide unlike physical quantities.

However, "ten dollars per day" is generally regarded as a permissible and understandable as well as an interesting expression.

That all rates are time rates.

That an automobile is equipped with only one device for producing acceleration, namely, the foot throttle.

That a flywheel bursts "because of centrifugal force."

That rubber is more elastic than steel.

That the difference between a "centigrade thermometer" and a "Fahrenheit thermometer" is more fundamental than the difference between, say, a mercury-in-glass and an alcohol-in-glass thermometer.

More generally, the tendency is to believe that the question of the particular system of units to be used in measurements is more fundamental than the choice of the operations and materials used to carry out the measurements.

That "sunlight is composed of seven colors which cannot be analyzed further."

This statement actually appears in a science textbook.

That white light is pure sunlight—pure solar radiation.

That nature *obeys* scientific laws.

That physical phenomena are more complicated than, say, social phenomena.

The distinction between complicated phenomena and highly developed knowledge of relatively simple phenomena is not well understood.

That science is infallible.

That one can get something for nothing.

That the fact that certain theories and explanations formerly taught in physics have been modified or abandoned shows that physicists are no more sure of what they are doing or where they are going than are the workers in any other field of knowledge.

That explanations of everyday phenomena are neither as interesting nor as useful as those of unusual phenomena.

In one respect the beginner is right. Phenomena to which we are accustomed we scarcely notice; only when they are placed in contrast to something to which we are unaccustomed do they develop intellectual significance. Almost every motive that leads us to modify and transcribe our thoughts proceeds from that which is uncommon and not understood.

That the ability to perform "lightning" calculations is a necessary, or even sufficient, characteristic of a first-rate mathematician.

Gymnastics, speedy technics and feats of endurance usually have the edge on creative effort in winning popular applause.

That to solve a problem is generally more difficult and requires higher ability than to find and give the first clear statement of the problem.

A simple analogy is furnished by the example of medical diagnosis as compared with the treatment of an identified ailment.

That an exercise involving simple substitution in a formula constitutes a genuine problem.

That if one has seen or pronounced a word several times, it is no longer necessary to know what it means.

That physics is unimaginative, purely utilitarian and lacking in esthetic and creative elements, and hence has little in common with the fine arts and the humanities.

* * * *

The foregoing list has been confined mainly to misconceptions that are likely to prevail among people who have had little or no physics. In the next issue we shall continue with a list of misconceptions often acquired by students while taking the elementary course.—D. R.

Publicizing the Need for Physics Teachers

A ROSTER of physics teachers and assistants available in Western Pennsylvania and West Virginia is being prepared by the Western Pennsylvania and Environs chapter of the American Association of Physics Teachers. A suitable notice was published in both Pittsburgh and small-town newspapers, and within three days more than 40 persons sent in their names. The total number probably will reach 80.

Perhaps other chapters of the Association will be encouraged to prepare a similar roster.—O. B.

They could not understand this life that sought
Only to bear the torch and hand it on;
And so they made report that all the dreams
Of Tycho Brahe were fruitless; perilous too,
Since he avowed that any fruit they bore
Would fall, in distant years, to alien hands.

—ALFRED NOYES

Proceedings of the American Association of Physics Teachers

The New York Meeting, January 21–23, 1943

THE twelfth annual meeting of the American Association of Physics Teachers was held at Columbia University, New York City, on January 21–23, 1943. The presiding officer was Professor A. A. Knowlton, President of the Association.

Meetings of the Executive Committee were held on Thursday, January 21, at the Hotel Pennsylvania.

Sessions on Friday, January 22, were devoted to the following invited addresses:

Advanced instruction and research in mechanics. R. G. D. RICHARDSON, *Brown University.*

The teachers' training program as a professional activity in colleges. K. LARK-HOROVITZ, *Purdue University.*

The physicist in the new world. VERN O. KNUDSEN, *University of California at Los Angeles.*

The work of the Office of Scientific Personnel of the National Research Council. HOMER L. DODGE, *University of Oklahoma.*

Training physicists for war research. F. W. LOOMIS, *University of Illinois.*

Meteorology in the war effort. C. G. ROSSBY, *University of Chicago.* (Read by C. B. Allenderfer.)

Accelerated programs in physics. R. C. GIBBS, *Cornell University.*

Manpower and deferment. M. H. TRYTTEN, *University of Pittsburgh.*

The work of the War Policy Committee of the American Institute of Physics. PAUL E. KLOPSTEG, *Central Scientific Company.* (Read by H. A. Barton.)

Discussion period. Led by H. A. BARTON, *American Institute of Physics.*

The new spirit in American physics—Second Richtmyer Memorial Lecture of the Association. GORDON FERRIE HULL, *Dartmouth College.*

Following these sessions, Professor Worthing and President Knowlton presented the 1942 Oersted Medal to Professor G. W. Stewart; the addresses of citation, presentation and acceptance appear elsewhere in this issue. On Friday evening the Association, the American Physical Society and the American Society for X-Ray and Electron Diffraction joined in a dinner at the Men's Faculty Club, Columbia University.

Saturday, January 23, was devoted to the annual business meeting and to contributed papers. The titles and abstracts appeared in the February issue, page 46. Two of the papers—No. 3 and No. 5—were read by title.

Report of the Secretary

THE executive committee of the American Association of Physics Teachers met at the Hotel Pennsylvania, New York City, on January 21, 1943. Members present were: A. A. Knowlton and L. W. Taylor, presiding; Gladys A. Anslow, Vola P. Barton, T. D. Cope, R. C. Gibbs, K. Lark-Horovitz, Louise S. McDowell, R. F. Paton, F. G. Slack, R. M. Sutton and W. C. Wineland (proxy for O. T. Koppius). Other members of the Association present by invitation were H. A. Barton, H. L. Dodge, F. Palmer and M. H. Trytten.

Reports were heard from the chairmen of the following special and standing committees: Awards, A. G. Worthing; Letter symbols and abbreviations, H. K. Hughes; Membership, R. C. Gibbs; National defense, R. A. Patterson; Physics in medical education, W. E. Chamberlain; Readjustments of physics teaching to the needs of wartime, M. H. Trytten; Richtmyer memorial lecture, T. D. Cope; Teaching of physics in secondary schools, K. Lark-Horovitz; Terminology, D. Roller; Tests and testing, C. J. Lapp. Upon the recommendation of their chairmen, the special committees on National defense and on Readjustments of physics teaching to the needs of wartime were discharged. All other committees were authorized to continue work. The committee for the 1943 Richtmyer memorial lecture consists of G. E. Grantham, Chairman; T. D. Cope, C. J. Overbeck, F. Palmer and G. B. Pegram.

A report from the chairman of the Nominating committee for 1942, F. L. Brown, was read. President Knowlton had previously appointed J. E. Shrader, F. L. Nutting and M. R. Wehr as tellers for the 1942 election, and they had received the ballots and determined the vote as of January 5, 1943. However, approximately 40 additional ballots were received by the secretary after the foregoing count had been made. At the direction of the Committee, the chair named F. Palmer, Vola P. Barton and W. C. Wineland to receive all ballots from the secretary, to accept the count of January 5 and to add to the latter all votes since received from members in good standing. J. G. Winans was appointed chairman of the Nominating committee for 1943.

The secretary stated that all regional chapters had filed reports for 1942 and had named representatives on the executive committee for 1943.

Upon recommendation of the editor of the AMERICAN JOURNAL OF PHYSICS, J. D. Elder, Leigh Page, R. M. Sutton and E. C. Watson were appointed associate editors for the period 1943–1945. The editor reported that the previously authorized cumulative author and analytic subject index covering the first ten volumes of the journal is in preparation and will be published this year. The original plan to include an index to selected articles in other periodicals has been temporarily abandoned because of the pressure of war work.

T. D. Cope was nominated to succeed G. R. Harrison as representative of the Association on the governing board of the American Institute of Physics. H. A. Barton discussed the need for a joint resolution by the Association and the American Physical Society on wartime training of scientific and technologic personnel for services essential

to the war effort but not included in the armed forces. After some discussion the chair was instructed to appoint a Committee on resolutions to confer with representatives of the Physical Society and to prepare a resolution for presentation to the Association during its annual business meeting; the chair named R. C. Gibbs, chairman; F. Palmer and F. G. Slack.

It was voted to continue constituent membership in the American Council on Education during 1943, with R. M. Sutton, K. Lark-Horovitz and R. C. Gibbs as Association representatives. Representatives on the councils of the A. A. A. S. were appointed as follows: W. P. Davey and L. W. Taylor on the National council; L. E. Dodd and P. Kirkpatrick on the council of the Pacific Division.

It was voted that the passage in the Association By-laws which authorizes emeritus membership be interpreted to mean that emeritus members have the right to vote in elections.

Invitations to participate in summer meetings during 1943 were received as follows: at Corvallis, Oregon, June 14–19, in affiliation with the Pacific Division, A. A. A. S.; in Chicago, Illinois, June 18–20, with the Physics Section, S. P. E. E.; in a proposed summer meeting with the American Physical Society. It was voted that these invitations be accepted in principle and that the meetings be conducted if regional committees on arrangements are appointed by the Association officers.

The annual business meeting.—The twelfth annual business meeting convened in the Pupin Physics Laboratories, Columbia University, at 12:30 P.M., January 23, 1943. President Knowlton presided.

The actions taken by the executive committee at its meetings on January 21 were reviewed by the secretary and were approved without dissent. Similar action was taken on the reports of the treasurer [Am. J. Phys. **11**, 48 (1943)] and of the editor.

After hearing the report of the tellers, the chair ruled that the election had resulted as follows:

President: L. W. TAYLOR
Vice President: R. C. GIBBS
Treasurer (two years): P. E. KLOPSTEG
Secretary (two years): C. J. OVERBECK
Members of Executive Committee (two years): GLADYS A. ANSLOW, P. KIRKPATRICK.

The Committee on resolutions reported that, as directed by the executive committee, it had conferred with representatives of the American Physical Society and had prepared a resolution in which it is pointed out that the Army and Navy College Training Programs as so far announced provide for the training of technical personnel for use almost solely, if not entirely, within the armed forces; therefore, that other war agencies, such as war industrial, research and training staffs, are now confronted with the closing off of the usual avenues of supply of technically trained personnel; hence, that effective steps should be taken immediately to provide an over-all War Training Program to meet *all* the needs of the armed services, of war industry and of war research in scientific and technologic fields; and that adequate provision be made to insure such a flow of personnel trained in physics into war research, industrial and training staffs as will be necessary to prevent serious impairment of the critical services to be rendered by these agencies; finally, that copies of the resolution be sent to the Chairman of the War Manpower Commission, to the Secretary of War, to the Secretary of the Navy, to the Chairman of the War Production Board, to the Director of the Office of Scientific Research and Development and to the Chairman of the National Defense Research Committee. The resolution was adopted without dissent.

In view of the fact that the priority situation has not improved, the Association voted to reaffirm its action taken at Pennsylvania State College, June 26, 1942, to the effect that the American Institute of Physics, through its War Policies Committee, be asked to give special attention to the problem of securing adequate priorities for materials needed by educational institutions for repairs, replacements and developments of equipment used in teaching physics to students preparing for chemistry, engineering, medicine, dentistry, veterinary medicine, teaching of physical science, military and naval service and other callings essential to the war effort.

It was voted that the Association representatives before the American Council on Education be empowered to speak for the Association on the problem of federal aid for teacher training projects during the emergency.

By a rising vote the retiring secretary was thanked for his services to the Association. President-elect Taylor was then called to the chair, and a similar expression of thanks was accorded the retiring president.

THOMAS D. COPE, *Secretary*

ATTENDANCE

Members who registered at the New York meeting were:

Alice H. Armstrong, Wellesley College; E. F. Barker, University of Michigan; E. C. Barkofsky, Federal Telephone and Radio Laboratories; B. W. Bartlett, United States Military Academy; H. A. Barton, American Institute of Physics; V. P. Barton, Goucher College; P. F. Bartunek, Rensselaer Polytechnic Institute; Hilda Bass, Smith College; C. E. Bennett, University of Maine; H. Louisa Billings, Smith College; O. H. Blackwood, University of Pittsburgh; H. Branson, Howard University; G. P. Brewington, Lawrence Institute of Technology; Catherine L. Burke, Wellesley College; G. H. Burnham, American Institute of Physics; W. S. Burton, George School; B. Cioffari, College of New Rochelle; W. R. Cole, Lincoln University; T. D. Cope, University of Pennsylvania; R. T. Cox, New York University; S. W. Cram, Kansas State Teachers College; W. P. Davey, Pennsylvania State College; K. B. Demaree, McGraw-Hill Book Company; H. L. Dodge, Office of Scientific Personnel; Elsie M. Dollman, New York University; H. W. Farwell, Columbia University; R. C. Gibbs, Cornell University; M. C. Harrington, Drew University; C. L. Henshaw, Colgate University; Erna M. I. Herrey, Queens College; J. R. Hobbie, Skidmore College; G. F. Hull, Dartmouth College; A. B. Hussey, College of New Rochelle; M. C. Hylan, Rariton Arsenal; Bro. Godfrey John, La Salle College; G. E. C. Kauffman, Stony Brook School; E. C. Kemble, Harvard University; A. A. Knowlton, Reed College; V. O. Knudsen, University of California, Los Angeles; B. Kurrelmeyer, Brooklyn College; K. Lark-Horovitz, Purdue University; E. M. Little, Frankford Arsenal; F. W. Loomis, University of Illinois; Louise S. McDowell, Wellesley College; P. E. Martin, Muskingum College; A. B. Meservey, Dartmouth College; Helen A. Messenger, Hunter College; H. A. Miley, Camp Evans Signal Laboratory; Nora M. Mohler, Smith College; Rose C. L. Mooney, Newcombe College; R. Morgan, University of

Maryland; R. M. Morrow, Albion College; C. C. Murdock, Cornell University; F. Palmer, Haverford College; R. F. Paton, University of Illinois; E. M. Rogers, Princeton University; R. D. Rusk, Mt. Holyoke College; H. K. Schilling, Pennsylvania State College; R. S. Shaw, College of the City of New York; A. W. Smith, Ohio State University; G. W. Stewart, University of Iowa; W. W. Stifler, Amherst College; Hildegard Stückler, Mt. Holyoke College; R. M. Sutton, Haverford College; L. W. Taylor, Oberlin College; F. H. Trimble, Armour Research Foundation; M. H. Trytten, University of Pittsburgh; Katherine M. Van Horn, New Jersey College for Women; P. L. Vissat, Cornell University; L. R. Weber, Colorado State College; Dorothy W. Weeks, Wilson College; M. W. White, Pennsylvania State College; W. C. Wineland, Morehead State College; K. S. Woodcock, Bates College; J. W. Woodrow, Iowa State College; A. G. Worthing, University of Pittsburgh; J. Zeleny, Yale University; G. E. Ziegler, Armour Research Foundation; R. A. Boyer, Muhlenberg College; J. A. Duncan, U. S. Naval Academy; J. R. Lawson, Fisk University; A. Spector, Queens College.

Body and Soul—A Message from President L. W. Taylor

THE science of physics is experiencing an opportunity for immediate and desperately needed service such as few of us ever foresaw. Before this war is over, it will be possible to say of physicists what Churchill said of the English fighter pilots: "Seldom have so many owed so much to so few." In their gratification at this opportunity, physicists, more especially teachers of physics, must not overlook an accompanying responsibility.

Just at present the overwhelming demand is for gadgets and trained men to operate them. These we must provide, notwithstanding a ten-to-one handicap. Yet if we do not go beyond this we shall but contribute to a serious and widespread misapprehension. The general public, insofar as it has any impression about physics at all, is inclined to picture physicists as a group of high-grade electricians and mechanics. This function we can perform, to be sure, and perform effectively. But there is some danger that our satisfaction in playing a mechanician's role, urgent though it is just now and in the immediate future, may cause us to overlook a more important long-range function.

The principal significance of physics during the last 350 years has not been the production of gadgets, overwhelming though the volume of invention has been, but rather the provision of the soil in which the spirit of discovery and invention could thrive. This will be as true for the future as it has been for the past. Some vision of this must have prompted Dean Knudsen at the last annual meeting when he said:

> Physics must become more than a source of mere mechanical technics and gadgets. It must, I believe, contribute consciously to the science of values.

While physicists dislike to deal explicitly with their value concepts, the fact is that without one such concept, *utter fidelity to observable fact*, as its starting point there could be no such thing as science. Though this may at first appear to be a truism, there are some common fields where fidelity to observed fact is more likely to be rated a vice than a virtue. The great contribution of the sciences, pioneered by physics, to the world of intellectual endeavor lies in putting fidelity to observable fact ahead of every other consideration.

Not that the sciences possess now, or ever did possess, a monopoly on fidelity to fact. Still less that individual men of science are always exemplars of that virtue. But the sciences constituted the first large section of the intellectual world to make such fidelity its point of departure and principal criterion of acceptable work. This is the point of greatest significance in the sciences, rather than the array of discoveries and inventions that so impresses the proverbial man on the street. To the extent that we as teachers use traditional classroom material as a culture medium for the growth and spread of fidelity to observable fact, to just that

extent shall we be meeting our highest professional responsibility.

Professor Hocking stated a profound truth when he said:

> We are scientific people and we want our students to feel the enthusiasm and promise of the scientific method. We want them to feel the moral quality of exact technic, as exact as the subject matter permits. We want them to feel that science is a spiritual enterprise.

For the cultivation of this ideal, physics—as the pioneer science—possesses a primary responsibility.

Let us as physicists bend every energy to our major part in winning this war. Let us as teachers marshal every resource to the prosecution of effective instruction in our subject, both now and after the war is over. Let us as aspiring human beings make all these efforts count toward the attainment of the values for the cultivation of which we share, with our colleagues in other intellectual areas, a responsibility to all peoples and all times.

DIGEST OF PERIODICAL LITERATURE

A Heat-Sensitive Liquid

A little crystalline cobalt chloride is dissolved in colorless industrial alcohol, and water is added a drop or two at a time until the deep blue liquid just turns pink. This liquid changes sharply in color when heated and returns to its original color on cooling; hence it is useful in convection experiments. The motion of the liquid may often be made clearer if one drop of ammonium hydroxide solution is added, so that flocculent particles of cobalt hydroxide are formed.—H. G. ANDREW, *Sch. Sci. Rev.* **24**, 82 (1942).

J. D. E.

Static Determination of the Components of the Earth's Magnetic Field Strength

This method of finding H and V is a modification of one due to Toepler (1884). An iron rod is attached with its axis vertical to the pointer of a balance, made of nonferrous material, at such a height that the center of gravity of the system is near the knife-edge but below it. The beam is alined in the magnetic meridian. The iron rod is magnetized by means of a solenoid or by two bar electromagnets placed in contact with its ends, and the beam is balanced with the rider. The rod is then magnetized in the opposite sense and the rider is shifted to restore equilibrium. The product of the weight of the rider and the change in its position is equal to $2MH$, where M is the magnetic moment of the magnet. If the experiment is repeated with the iron rod horizontal, the corresponding product gives the value of $2MV$. If now the value of M/H is known from a deflection magnetometer experiment, the values of both H and V can at once be found. The present method does not involve the moment of inertia of the magnet; it clarifies the concept of magnetic moment; and it emphasizes the fact that the earth's field is not restricted to a horizontal plane.—E. J. Irons, *Sch. Sci. Rev.* **24**, 76–78 (1942).

J. D. E.

Inexpensive X-Ray Equipment for Demonstrations

Obsolete x-ray medical equipment may often be obtained from dealers at a fraction of the cost of new apparatus and is entirely suitable for lecture demonstrations. A suggested set-up consists of two Crookes' tubes and a Coolidge tube in series, operated from an oil-immersed high voltage transformer that contains a built-in filament transformer for the Coolidge tube. The high voltage and the current are controlled by an autotransformer and a resistor, respectively, connected in the primary circuit. The high tension lines may safely be carried by clean wooden support stands.

In this set-up the Coolidge tube is used both for the production of x-rays and as a rectifier for the Crookes' tubes. It was found that the electron beams produced in this way are much sharper than those produced with the aid of an induction coil.—C. L. CHRIST, *J. Chem. Ed.* **19**, 548 (1942).

J. D. E.

A Projection Manometer

A manometer that can be used in place of the slide holder of a projection lantern is useful for lecture demonstrations. An 18-in. length of 6-mm glass tubing is bent into the shape of a square **U**, the bottom of which is about 4 in. long. The tube is mounted with the arms horizontal between two pieces of 1.4-in. plywood, in each of which has been cut a rectangular window. The pieces of plywood are separated by wooden spacers, and the bottom of the

U is opposite the windows. The dimensions of the apparatus are such that it will replace the slide holder in the lantern.

A piece of transparent ruler may be mounted beside the bottom of the U—which is vertical—to serve as a scale. The lower arm of the manometer may be attached either to a vertical thistle tube containing a liquid or to a tube passing through a stopper into liquid in a flask. In the latter case the pressure in the flask is observed. If, however, the flask is connected to the system under observation by another tube through the stopper, a third tube provided with a stopcock may be used to control the position of the meniscus in the manometer without appreciably disturbing the system.—J. W. MOORE and C. M. FURGASON, *J. Chem. Ed.* **19**, 513 (1942). J. D. E.

An Atomic Structure Chart

Numerous methods have been suggested for constructing a chart of the elements that would be superior to the original Mendeleeff periodic table, but to all of them there have been objections. However, a chart can be made that "overcomes all seven of the defects of the atomic number charts without introducing any new difficulties and, in addition, combines the quantum number table with the periodic system." This chart is based on the electronic structure of the elements; the position of an atom in the chart is given by plotting the location of its differentiating electron, namely, "the additional electron which makes an atom different from the atom of the preceding element in order of increasing atomic numbers." The shell in which the differentiating electron lies—that is, the principal quantum number n—is taken as the ordinate; the number of the electron in that shell is the abscissa. The elements fall into three groups: the "representative elements," in which the differentiating electron is in the outermost shell; the "related metals," in which it is in the second from outermost shell; and the rare earths, in which it is in the third from outermost shell. Thus the rare earths find their proper place in the chart. The fact that there are breaks in the order of atomic numbers in this form of chart is not disturbing, for the electron configuration of an atom is chemically more fundamental than atomic numbers.—W. F. LUDER, *J. Chem. Ed.* **20**, 21–26 (1943).

J. D. E.

A Simplified Electronic Thermoregulator

A small thyratron—the 2A4G—can be used in place of the more common relay to control the heating current for maintaining the temperature of a small water bath. In the present application, the bath required 10 to 15 w of energy and the temperature was kept constant to within 0.05°C. The circuit is controlled by means of a mercury-toluene thermoregulator. The mercury contact does not oxidize because it carries only the very small grid current of the thyratron, and the relay contacts are eliminated.

The circuit in its simplest form is shown in Fig. 1. If the mercury contacts are open, the grid is at cathode potential and the plate current will be directed through the 2000-ohm heating coil during the half-cycle in which the plate is positive. When the mercury column rises to close the contacts the grid is brought to a negative potential during the part of the cycle when the plate is positive, and thus prevents conduction. This action is the result of the fact that the ends of the high voltage winding of the transformer are 180° out of phase with respect to the center tap.

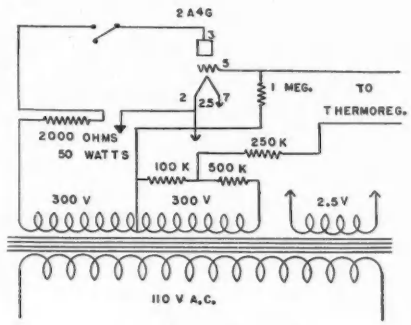

FIG. 1. Diagram of circuit.

The circuit may be safeguarded against tube failure by using two thyratrons in parallel, the grid of one being connected to the cathode of the other through a 1-megohm resistor and an 11.3-v winding on the transformer. One of the tubes will operate in preference to the other until it fails, whereupon the second tube will function, thus providing an indication of the failure of the first.—W. E. GILSON and H. A. WOOSTER, *J. Chem. Ed.* **19**, 531–2 (1942).

J. D. E.

A World Language

In the interest of international communication and free expression of ideas, it is hoped that scientific organizations will assist in the movement toward an agreed auxiliary language that can be easily learned and used by all civilized peoples of the world. The International Morse Code is an example of an accepted system of alphabetical and numerical communication, and the need now is for an auxiliary vehicle of language that will be as widely understood.

In 1921, a representative committee of the British Association published a careful and comprehensive report on this subject. After giving unanimous approval to the desirability of an international auxiliary language, the Committee considered the relative merits of three types: (i) a dead language, perhaps Latin; (ii) a national language, say, English; (iii) an invented language, for example, Esperanto or Ido. After careful consideration of evidence provided by experts, the Committee reached conclusions that briefly are as follows: (i) Latin is too difficult to serve as the desired language, and its disadvantages outweigh its advantages; (ii) the adoption of any modern national language by the common consent of the chief nations is unlikely, as it would confer undue advantages and excite jealousy, however impartial the promoters of the language might be; (iii) an invented language constructed on scientific principles and adaptable to many diverse require-

ments is a practicable means of international communication; it is neutral and has advantages of simplicity not possessed by most national languages. What invented language will meet with general approval remains to be decided by international agreement.

A British Association committee on post-war university education has recently recommended that apart altogether from the academic study of language and literature, every university should require its students to be able to speak and write an auxiliary international language. A simple common language is one of the best ways of promoting world-wide interrelationships; its construction should not be beyond the power of responsible literary, scientific and commercial authorities working cooperatively.—R. GREGORY, *Nature* **150**, 622 (1942). D. R.

Will School Mathematics Survive the War?

Soon after Pearl Harbor the educational world was badly jarred by the widespread protests of the Army, the Navy and the technical schools against the mathematical deficiencies of most high school graduates. The Progressive educationists held their peace while the associations of mathematics teachers move to raise their standards and many colleges took advantage of the situation to strengthen their mathematics departments. The chief "reform" was the introduction of "sub-freshman" courses to atone for high school deficiencies. Many teachers and conservative educators hoped that this might be one of the few minor blessings of war—a permanent recovery of the former position of elementary mathematics in general education.

But the Progressives are beginning to move again. Possibly the first symptom of revival was the suggestion, voiced deferentially here and there, that while the war demands for mathematical training must, of course, be met, all experienced teachers would realize that this was simply a temporary situation; when the emergency was over, they would, as a matter of course, revert to the teaching practices and traditions that had proved so satisfactory during the Progressive era. Recent educational conventions show a somewhat different line of attack. The necessity of meeting war needs in the field of numbers is frankly and patriotically recognized. It is suggested that these urgent requirements should be met by concentrating mathematics teaching upon practical, mechanical problems—aerodynamics, navigation, surveying, and so forth—avoiding any general treatment of mathematical theory. This means, of course, that high school students will be merely taught, verbalistically, without any comprehension of the principles involved, how to work certain types of problems by rule-of-thumb formulas. It ignores completely the fundamental, educational role of mathematics in developing a sound, scientific, rational philosophy of life. It also leaves it perfectly obvious that, as soon as the emergency is over, these special types of mathematical instruction will be superfluous, and can be dropped without any fuss. Teachers will need to rally all their resources of influence and persuasion if the war is to result in any permanent improvement of the sadly neglected mathematical education of the general public.—G. WAKEHAM, *Sch. and Soc.* **56**, 554–555 (1942). D. R.

Suggestions on Ways to Increase Wartime Physics Teaching Capacity

As soon as the Army and Navy training programs are in full operation there will be an unprecedented demand for teachers of physics. Although the institutions participating in these programs have already had their ranks seriously depleted, there remain two sources of teachers that should not be overlooked. The first source is the nearby institutions that will not have Army and Navy programs. Although such institutions should continue to teach physics to as many students as possible—particularly since the needs of war research, industry and teaching must be satisfied mainly by those who are ineligible for military service—nevertheless, some physics departments will find it impossible to continue in operation and their staff members should be added to departments in need of their services.

A second source of supply is within the institution itself. Many college teachers of other subjects have sufficient knowledge of physics so that, with some brushing up and observation of good teachers at work, they can become proficient instructors of beginning physics. These men and women should be found at once and encouraged to prepare for the teaching service which they will almost certainly be called upon to perform either in their own institutions or elsewhere.

Another consideration to be kept in mind by departments in making adjustments to the present situation is that all teaching and research must be directed to war ends. Advanced undergraduate and graduate work will soon make only small demands on staff time except in the few institutions where the Army and Navy programs will call for advanced work. Therefore, in many institutions there will be physicists who can serve the war effort better by going into war research than by teaching beginners. Institutions must release such men freely and replace them from the two sources already mentioned. Since there seems to be no hope that the present and future needs for war research will be satisfied, all physicists who are as good research men as they are teachers of beginners are urged to send notice of when they will be available to the Office of Scientific Personnel, 2101 Constitution Avenue, Washington, D. C. The office will facilitate adjustments in every way possible if they cannot be worked out locally and will be glad to receive information regarding institutional needs and available personnel. However, it will attempt to prevent bidding among institutions in mad competition for personnel. It is to the interest of all concerned that a sufficient supply of teachers should be developed and that the necessary adjustments be made easily and efficiently.—H. L. DODGE, *Science* **97**, 16–17 (1943).

Note. Much thought is being given to ways of increasing the total instructional capacity in physics. Thus, some institutions are offering refresher courses in physics to faculty members who normally are in other departments. It is also possible to experiment with revised schedules, makeshift laboratory equipment and other temporary expedients. Readers who have given thought to this problem are invited to submit letters for publication under "Notes and Discussion." A prompt exchange of views might prove to be quite valuable.—D. R.

Check List of Periodical Literature

Cosmic emotion. P. R. Heyl, *Sci. Mo.* **55**, 558–565 (1942). Wonder, curiosity, reverential awe and physical insignificance have been features of man's cosmic emotion since earliest times, and bid fair to remain so as long as our race shall last. A fifth element, superstitious fear, has now almost faded away.

Problem of the expanding universe. E. Hubble, *Sci. Mo.* **56**, 15–30 (1943). A brief description of the observable region of space, of the current theory of the expanding universes of general relativity, and of recent, more accurate observations designed to clarify and test the theory.

Science in the newspaper. B. J. Novak, *Sci. Ed.* **26**, 138–143 (1942). An analysis of the science content of the *New York Times* for the years 1930, 1933, 1936 and 1939. Of 15 science topics, health and medicine averaged 20 percent of the total space devoted to science; communication and transportation was second, with about 9 percent; atomic and theoretical physics was ninth, with 6 percent; light, heat, sound and electricity was eleventh, with 5 percent; mechanics was last, with 2 percent. The space was about equally divided between biological and physical science.

Newton after three centuries. E. T. Bell, *Am. Math. Mo.* **49**, 553–575 (1942).

The functions and performance of the eye. W. D. Wright, *J. Sci. Inst.* **19**, 161–165 (1942). A simple account of the eye and the visual processes, with some data on the remarkable efficiency of the eye under good observing conditions. "It is unfortunate that physicists are not, as a rule, very familiar with the operation and performance of the eye, in spite of their intensive efforts to outdo that organ."

The teaching of natural sciences and mathematics. S. R. Powers, *et al.*, *Rev. Ed. Research* **12**, 362–450 (1942). Reviews and selective bibliographies of recent investigations in science education.

Some college students describe the desirable college teacher. E. E. Lamson, *Sch. and Soc.* **56**, 615 (1942). A group of seniors at New Jersey State Teachers College assigned the following relative ranks to qualities which they valued most highly in a college professor: possession of expert knowledge, 49; vital personality, 46; fairness and impartiality, 45; ability to organize and instruct, 40; ability to get along with students, 33; sincerity and honesty, 23; sense of humor, 17; appearance, 13.

Science and government. H. G. Moulton, *Science* **96**, 523–527 (1942). What scientists can and cannot do to further the development of science in government, by the President of the Brookings Institution.

On numbering book illustrations. L. G. Westgate, *Science* **96**, 581 (1942). Reader time and irritation would be saved if illustrations in physical science textbooks were numbered, not consecutively, but according to their page number; thus, an illustration on page 32 would be Fig. p. 32, or even Fig. 32.

Science, common sense and decency. I. Langmuir, *Science* **97**, 1–7 (1943). "The mistaken over-emphasis on convergent phenomena in human affairs and the reliance on so-called scientific methods have been responsible in large degree for much of the cynicism of the last few decades. . . . Since we have to live with our minds, we should train them, develop them, censor them—but let us not restrict them by trying to regulate our lives solely by science or by reason."

Simplified photomicrography with a hand camera. R. P. Loveland, *Science* **97**, 24–26 (1943). Almost any ordinary camera can be used without mutilation and with the camera available immediately for other purposes. The optical efficiency of the method is high; the definition of the pictures is equal to that obtained with professional equipment.

Rutherford: life and work to the year 1919. H. R. Robinson, *Nature* **150**, 591–593 (1942). First Rutherford memorial lecture of the Physical Society.

New methods of calculating illumination. P. Moon, *J. Opt. Soc.* **33**, 115–122 (1943). An evaluation of recent improvements in the theory of illumination calculations in their relation to the general subject of photometrics. "Photometrics should be developed as a complete discipline, with methods of the greatest generality from which all special cases can be derived. There is nothing of the kind at present."

Benjamin Franklin and the mysterious "Dr. Spence." I. B. Cohen, *J. Frank. Inst.* **235**, 1–25 (1943). The date and source of Franklin's interest in electricity.

Limitations of visual education. H. J. Gilkey, *J. Eng. Ed.* **33**, 426–431 (1943). The function served by motion pictures and similar visual aids is useful but limited.

Flux calculations in optical systems. A. C. Hardy, *J. Opt. Soc.* **33**, 71–74 (1943). The calculation of the flux content of an optical image may be likened to a calculation based on Ohm's law for a simple series circuit: the brightness of the source plays the role of emf; the limiting aperture is analogous to resistance; and the flux content of the image is determined almost as simply as the electric current. "The validity of this analogy is unfortunately discredited by the attention devoted to Ohm's law in even the most elementary physics textbooks and the omission of the corresponding material pertaining to optics."

The instantaneous motion of a rigid body. D. Jackson, *Am. Math. Mo.* **49**, 661–667 (1942). A suggested method of presentation.

Sirens and bels. J. O. Perrine, *Sci. Mo.* **56**, 145–154 (1943). The power of the sound emitted by the Chrysler-Bell super-siren is 42.2 kw, and the intensity at 1 mi is 10 bels. A 30-in. rotating plate at 4400 rev/min has six holes that interrupt blasts of air from six 2×2-in. throats. The total air current is 2500 ft^3/min at 5 lbwt/$in.^2$ The article presents interesting data on sound intensities due to various modern sources.